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NRL Memorandum Report 3795

AD A058589

Shock and Vibration Performance of an Epoxy Chocking Compound Chockfast Orange, PR-610CF (Philadelphia Resins Corp.)

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LEVEL II

June 1978

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NAVAL RESEARCH LABORATORY
Washington, D.C.

(18) SBIE (19) AD-E000 202

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NRL Memorandum Report 3795	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) SHOCK AND VIBRATION PERFORMANCE OF AN EPOXY CHOCKING COMPOUND CHOCKFAST ORANGE, PR-610CF (PHILADELPHIA RESINS CORP.)		5. TYPE OF REPORT & PERIOD COVERED (9) Final Report, October 1976 - September 1977
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) E. W. Clements		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Research Laboratory Washington, D. C. 20375		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS N651977P070058
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Ship Engineering Center Code 6101E Washington, D. C. 20362		12. REPORT DATE (11) June 1978
		13. NUMBER OF PAGES 43
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) (14) NRL-MR-3795		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

(12) 44p.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Shock
Vibration
Epoxy
Chocks

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In recent years, some equipment items have been installed on board Navy combatant vessels with chocks cast from epoxy chocking compounds. Since Navy combatants are characterized by severe shock and vibration environments, it is necessary to demonstrate that epoxy chocks can tolerate such environments. This report describes a series of tests in which structures resembling shipboard equipment items in mechanical features were mounted on epoxy chocks cast from one of the commercially available compounds. These structures were subjected to shock and vibration

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S/N 0102-014-6601

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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20. Abstract (Continued)

tests in accordance with the specifications required for acceptance of equipment items for installation on Navy combatants. These tests had no effect on the chocks which would be likely to impair their function. Damage was limited to some minor cracking and fragmentation which did not extend into load-bearing areas. It is conceivable, however, that installation between very flexible members could lead to more wide-spread cracking and fragmentation. The use of chocks of any description may also have the effect of introducing a spring element into the equipment foundation, and the potential influence of this on the equipment response to shock and vibration excitation should be considered.

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SHOCK AND VIBRATION PERFORMANCE OF AN EPOXY CHOCKING COMPOUND CHOCKFAST ORANGE, PR-610CF (Philadelphia Resins Corp.)

Objective

Test structures resembling some equipment items installed on Navy combatant ships have been mounted on Chockfast Orange chocks and subjected to the shock and vibration test environments required for equipment installed on Navy combatants. This report describes the effects of these tests on the chocks.

Background

Recent years have seen increasing use of epoxy chocking compounds on merchant ships and in shore installations. Since epoxy chocks are cast in place, they provide a much closer fit (and over a much greater area) to mating surfaces than can be practically achieved with machined chocks, and they require little in the way of surface preparation. More recently, epoxy chocks have been used to a limited extent on board combatant vessels.

While epoxy chocks may be convenient and economical, and perform well in ordinary usage, conditions aboard combatant vessels are more stringent. Combatants must be able to run at high speed for extended periods, and to shoot and be shot at. This requires that equipment and installations aboard these vessels must survive exposure to the severe shock and vibration environments which result. It is thus necessary to establish that epoxy chocks can themselves tolerate such environments, and also that they do not behave in a way which could impair the functioning of equipment items mounted on them.

Description of Auxiliary Tests

Since Navy operations range from the tropics to the poles, the effect of temperature on chock performance is a matter of concern. It is not possible to control the test temperature at the Naval Research Laboratory (NRL) Shock and Vibration Lab, so a group of auxiliary tests were devised to evaluate this effect. These tests were carried out by the Nonmetallic Materials Branch, Naval Surface Weapons Center, White Oak, Silver Spring, Md., and consisted of tests of compression strength (ASTM D 695, Ref. 1) and Izod impact strength

Note: Manuscript submitted May 24, 1978.

(ASTM D 256, Ref. 2) conducted at temperatures of -40, 70 and 120 F. For these tests, a quantity of the epoxy compound was furnished NSWC, and it was mixed, poured, and cured following manufacturer's recommendations. Test specimens were machined from the cured material, brought to temperature and tested at temperature. Another temperature effect of interest, that of possible degradation due to prolonged exposure to extreme temperatures, was not investigated due to time limitations.

Results of Auxiliary Tests

Izod impact strength was found to change relatively little with test temperature, but at 120 F. was still well above that required by probable service loadings.* It was concluded that test temperature per se would have no significant effect on chock performance. Test results are summarized in Table I.

Table I

Test Temperature	Compressive Strength	Izod Impact Strength
F	psi	ft - lb/in
-40	25930	0.325
70	18740	0.396
120	14944	0.374

It was observed that the material had a porous structure, and that its properties might be improved by preparation in vacuo. Since this is not done for normal applications, it was not done for these tests.

Description of Shock and Vibration Test Structures

Two test structures were built which roughly resembled equipment items that have been installed on Navy combatant vessels with epoxy chocks. Each test structure consisted of a mounting ring and a mass lump connected by four legs of car - building channel, constructed as an all-steel weldment. The test structures resembled the real items in total weight, height of center-of gravity above the mounting configuration and chock geometry. Some extra features were added in order to extract more information from the test results. The mounting rings were flame-cut from as-rolled 3/4 - in. plate and drilled through with clearance holes for the hold-down bolts. No other

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* Translated to the test structures used for shock tests, which are representative of combatant installations in terms of bearing load, the lowest measured compressive strength would imply a static acceleration capacity of about 4000 g (compressive strength X chock area/ structure weight). The static acceleration equivalent to the standard shipboard shock test is 100 or 200 g.

machining was done, so that the mounting surfaces mating to the chock material were rough-textured, wavy from welding the legs to the mounting rings and had irregular edges from the flame - cutting. The bolt holes around one half of each mounting ring were spaced on the center line of the ring, while those around the other half were located on a circle one bolt diameter in from the outside edge. Because of the four-leg arrangement, the inertial loading pattern of each structure was strongly non-uniform around its mounting ring, and each structure was expected to show a first horizontal resonance in the 16-25 Hz range. This is the range of frequencies in which the highest acceleration inputs are imposed on a test item by the standard Navy shipboard vibration test (MIL-STD-167-1, Type I) (Ref. 3). The responses of the test structures themselves were determined by exploratory vibration tests without chocks, where the mounting rings were bolted down solidly to a 3/4 inch mounting plate.

Test Structure No. 1

The total weight of this structure is 920 lb, and its center of gravity is located 37 in. above its mounting surface. Its legs are 4 in. car building channel, and its mounting ring 2 3/4 in. wide with an inner radius of 6 3/4 in. Eighteen 21/32 in. dia. holes provide clearance for 5/8 - 11 hold down bolts. Test Structure No. 1 is shown in Fig. 1 just after removal of the damming material from the cured chocks. Its overall height is 47 1/2 in. from the mounting plate to the top of the mass lump. Because of its symmetry, the directions chosen for horizontal vibration tests were those which directed the vibration axis through two opposite legs ("Horizontal 90°") and between pairs of adjacent legs ("Horizontal 45°"). For the exploratory vibration tests to determine the characteristics of Structure No. 1 itself, the mounting ring was bolted down directly to the 3/4 in. mounting plate. In the vertical direction, a resonance was found at 39 Hz with a Transmissibility Ratio (TR)* of 1.05:1. In both horizontal directions a first resonance was found at 13.5 Hz, with TR of about 4:1. Principle resonances were found at 23 Hz for Horizontal 45° and 25 Hz for Horizontal 90°, with TR of 10:1 in each case.

Test Structure No. 2

Test Structure No. 2 is an enlarged version of No. 1. Its total weight is 1675 lb, and its center of gravity is 81 inches above

* Transmissibility Ratio: the ratio of amplitude of motion measured at the mass lump in the nominal direction of motion to the amplitude of motion measured at the test machine table in the nominal direction of motion without regard to phase, spectral purity, or possible motion in directions other than the nominal.

mounting surface. Its legs are made from 6 in. car-building channel, and its mounting ring is 3 1/2 in. wide with 14 in. inner radius. Clearance holes for the eighteen 3/4 - 10 hold-down bolts are 25/32 in. diameter. Structure No. 2 is shown in Fig. 2, with overall height from mounting plate to top-of-mass lump of 90 3/4 in. Vertical resonances were found at 25 Hz, TR 1.3:1, and 47 Hz, TR 1.6:1. For both horizontal directions, first resonance was found at 14 Hz, TR 4.5:1. Major resonances were 25 Hz, TR 10:1 for Horizontal 45° and 27 Hz, TR 8:1 for Horizontal 90°.

Chock Preparation

The chocks for the two Test Structures were prepared following the same general procedure, but at different times, as all testing of Structure No. 1 was completed before the chocks of Structure No 2 were poured. All preparations took place in a lab space temperature-controlled to 74 ± 2 F. All tools and materials were placed in this space several days previously so that they would come to temperature before assembly and preparation. The procedure was in accordance with the recommendations of, and made use of tools and materials supplied by, the manufacturer of the chocking compound. The latter consisted of a mixing tool, a spray-on mold release agent, and a non-melting silicone grease. The mold release was sprayed on all metal surfaces with would be in contact with the chocking compound - the top of the mounting plate, the bottom of the mounting ring, the inner sides of the circumferential dams, and the sides of the spacer bars. The spacer bars were steel bar stock 3/4 in. X 1/4 in., cut in lengths equal to the width of the mounting ring plus 1/2 inch. They were machined with a few mils taper to the 1/4 in. dimension to facilitate removal after the chocks had cured. For each test structure, nine spacer bars were laid on edge on the mounting plate so that they were radial to the mounting ring when the test structure was set down on them, with two hold-down bolt holes between each pair of bars. The test structure was then rested on them, and the hold-down bolts passed through the clearance holes in the mounting ring and threaded into the mounting plate and tightened securely, but to no particular torque. In the 3/4 in. region where the bolts would be in contact with the chocking compound, their threads were filled out to body diameter with the non-melt silicone grease. For Test Structure No. 1, all eighteen of the hold-down bolts were greased in this way, and some variation was found in the success with which the grease prevented intrusion of epoxy into the threads. For Test Structure No. 2, half of them were greased, and alternated with bolts fitted with lengths of thin-wall Teflon tubing. The tubing was found to be more convenient and uniformly effective. Circumferential dams were formed from strips of 1/16 in. sheet metal 1 1/4 in. wide. One of these was pressed against a circumference of the mounting ring, to which the ends of the spacer bars were flush. The other was tightened against the other ends of the spacer bars, which protruded 1/2 in. beyond the other circumference of the mounting ring. The overall arrangement, for each test structure, formed nine chock pads 3/4 in. thick

which completely supported the mounting ring save for 1/4 in. separation between pads. Each pad contained two hold down bolts, and had an overpour space 1/2 in. wide by 1/2 in. high to ensure that the pad volume was completely filled. Due to the overpour space, each pad had a segment 1/2 in. wide and 1 1/4 in. high outside its load-bearing area. For Test Structure No. 1, these overpour regions were on the outer side of the mounting ring. For Test Structure No. 2, they were on the inner side to bring the hold-down bolts closer to the edge of each chock pad. The chocking compound was furnished on a two-component (filled epoxy and hardener) system in one-gallon units. One of these units was mixed and poured immediately, then another mixed and poured until the dammed volume was completely filled. Mixing was done using a mixing tool, furnished by the manufacturer, and held in a low-speed (200 rpm nominal) hand-drill. After pouring, the test assemblies were left untouched for seven days, and were then disassembled for inspection and photography of the chock pads. When disassembly was attempted with Test Structure No. 1, it was found that in some places the overpour region had adhered to the outer edge of the mounting ring. Since the overpour regions at this stage formed a continuous ring, the chock pads were firmly attached to the mounting ring until a groove was cut in the overpour to free the adhesions. After this was done, the test structure was lifted off the chock pads, the spacer bars were slipped out and the chock pads separated by cutting the overpour ring with a bandsaw. Figure 3 shows a detail of the chock pads of Test Structure No. 1 after the circumferential dams had been removed, and Figure 4 shows them after they had been cut apart. Each chock pad was numbered and referenced to fiducial markers on both mounting ring and mounting plate, so that throughout this and subsequent disassemblies and reassemblies each pad remained between the proper mating surfaces. Several features of Figure 4 are worth noting. The bearing surfaces of the chocks are quite rough and porous, and show several good-sized voids, particularly the upper left corner of Pad 1. The surfaces of the overpour regions, on the other hand, are smooth, implying little lateral mobility of bubbles of entrained air or evolved gas.* The groove cut to release the test structure can be seen at the inner edge of the overpour region. Since only a small amount of the total overpour height was removed, it seems likely that the mold release agent had not been applied uniformly over the surface of the mounting ring's edge. Any local upward taper of the mounting ring's outer edge would also contribute to difficulty in disassembly, but no consistent taper in either direction was apparent.

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* Subsequent discussion with manufacturer personnel indicated that the mixing speed may have been higher than optimum, leading to more entrainment of air than usual. For Test Structure No. 2 the compound was mixed at about 100 rpm. The chock pads for this structure showed somewhat less, but still substantial, porosity. See Figs. 6 and 7.

Finally, Figure 4 reveals some chipping and spalling in the overpour regions (Pad 7, particularly) which occurred when the pads were cut apart. Figure 5 shows the mounting ring and chock pads of Test Structure No. 2 after removal of the circumferential dams, and Figure 6 the top and Figure 7 the bottom surfaces of the chock pads after disassembly and separation. The general appearance is much the same as that of the pads for Structure No. 1, with slightly less porosity. After inspection and photography, the test assemblies were put back together and the hold-down bolts tightened to the desired torque. The static bearing load on the chock pads due to the weights of the test structures were negligible, only a few psi in either case. A total static load of 700 psi was chosen as the middle of the range of static loads recommended by manufacturer, and the bolt torque required to produce the necessary bolt tension calculated and rounded. For Test Structure No. 1 this torque was 50 ft. lb., and for Test Structure No. 2, it was 150 ft. lb. Calculated total bearing loads were 714 psi and 715 psi respectively. The mounting ring/chock pad was felt likely to be fairly flexible in comparison to the bolt stiffness, so that the total bolt load could approach the sum of the static and dynamic loads. Accordingly, hex-socket cap screws were used for hold-down bolts because of their high strength. The completed assemblies were then transferred to the NRL Shock and Vibration Lab, where the ambient temperature varied from 80 - 90 F during the period of the shock and vibration tests.

Vibration Tests of Test Structure No. 1.

Vibration tests were conducted on the NRL 5000-lb Reaction-Drive Vibration Machine. This machine consists of a rigid test table weighing 6000 lb with a mounting area of 7 x 5 ft. The test table is supported by a cantilever spring at each corner, allowing free motion vertically and in the horizontal direction perpendicular to the axes of the springs - the long dimension of the test table lies in this direction - and very little motion in the orthogonal horizontal direction, which is along the axes of the springs. At each end of the test table is a vertical structure to which an NRL Three-Mass Reactive Force Generator is fastened. Each of these contains three rotating eccentric weights whose relative positions can be changed to control both the direction and amplitude of the motion of the test table, which is due to the reaction forces from the imbalance of the rotating weights. The generators can be raised or lowered along the end structures to align the reaction forces with the center of gravity of the test table/equipment combination for horizontal vibration. Tests were conducted in general accordance with MIL-STD-167-1, Type I (Ref. 3), which is the general specification for vibration testing of equipment for Navy vessels. The specification calls for vibration over the frequency range of 4 - 50 Hz in three orthogonal directions corresponding to the vertical, athwartship and fore - and - aft orientations of the equipment item as it would be installed aboard ship. For each of these directions, the test consists of three parts. The first is "Exploratory", where the vibration frequency is smoothly

varied from 4 - 50 Hz with a table excursion (peak-to-peak displacement) of 0.20 in. from 4 - 33 Hz and .006 in. from 34 - 50 Hz. The purpose of this segment of the test is to reveal resonances and give a general feel for the dynamics of the equipment. The second segment is "Variable Frequency", where the vibration frequency is increased in 1 Hz increments and each integral frequency is maintained for five minutes. Table excursion is 0.60 in. in the 4 - 15 Hz range, .040 in. for 16 - 25 Hz, .020 in. for 26 - 33 Hz, .010 in. for 34 - 40 Hz, and .006 in. for 41 - 50 Hz. Because of the greater excursion, resonances are sometimes found during this segment of the test which escaped notice during the Exploratory test. The final part of the test is "Endurance", where the vibration frequency is tuned to equipment resonance and maintained for a total of two hours minimum. Usually, there will be a principal resonance, so the full two hours dwell time is spent here. If two or more resonances of about equal importance are found, the two hours may be divided between them. If no resonance was found, the two hours are put in at a frequency of 50 Hz. Test table excursion at any frequency is to be the same as that specified for that frequency for the Variable Frequency test.

As noted above, the two horizontal directions "Horizontal 90°" and "Horizontal 45°" were chosen for test rather than the orthogonal directions, due to the symmetry of the Test Structures. Figure 8 shows Test Structure No. 1 mounted on the test table oriented for the Horizontal 45° test. Motion was measured with velocity pickups (not shown) bolted to the top of the mass lump of the test structure and to the test table of the vibration machine. The pickup outputs were fed into matching integrating vibration meters which give dial readings indicating peak-to-peak displacement of the associated pickup.

Vertical Direction - Exploratory

A slight resonance was found at 33 Hz, TR 1.3:1. This was slightly lower in frequency and slightly more pronounced than the 34 Hz, TR 1.05:1 which had been found when Test Structure No. 1 had been tested without chocks. However, no significant difference could be found in the amplitudes of motion measured on the mounting ring and on the mounting plate.

Vertical Direction - Variable Frequency

As the purpose of the test series was to exercise the epoxy chocks, the range of test frequencies was limited to include the principal resonance. For the vertical direction, the test range was 4 - 33 Hz. No unusual behavior was noted. The TR was found to increase slowly above 15 Hz, reaching a peak of 1.3:1 at 33 Hz.

Vertical Direction - Endurance

The two-hour endurance test was conducted at 33 Hz. No unusual behavior was noted.

Horizontal 90° Direction - Exploratory

Here a different behavior pattern from that found in the test without chocks emerged. The minor resonance at 14 Hz no longer appeared as a distinct peak, but blended into a general rise of TR which began at 8 Hz and was still rising at 23 Hz. The test was halted at this frequency because the TR was approaching 50:1.

Horizontal 90° Direction - Variable Frequency

As described above, the test table of the vibration machine is supported by springs so that it is free to move vertically and in one horizontal direction. The direction of motion is selected by orienting the reaction forces which drive it - there is no provision for constraint to force motion to be in the desired direction, because it is not ordinarily necessary. However, for horizontal tests of Test Structure No. 1, and to an even greater extent with Test Structure 2, it was found impossible to attain a simple, linear motion of the test table. Rotational and rocking modes of the test structure/test table ensemble were observed in various combinations throughout the frequency range. While this complex motion had been taking place during the Exploratory test, it was strikingly apparent during the Variable Frequency test, with its higher table amplitudes. Subsequently, Test Structure No. 1 was retested without chocks at the full test amplitudes specified for the Variable Frequency test.* A similar complex pattern merged rather than the simpler one originally found with the lower amplitude drive. While the complexity of the dynamical situation is such that it is difficult to evaluate the influence of the chock pads on the motion of the structure, they do seem to exacerbate the situation, since while the high amplitude behavior was complex both with and without them, at low amplitudes it was simple without them and complex with them. Whatever the influence of the chock pads may be on the environment presented to the mounted item, which is in itself something to consider seriously, there is no doubt that the behavior noted here presented a stringent environment to the chock pads, which was the principal concern of this test series.

This consideration was also deemed to justify departures from the nominal vibration test procedure specified by MIL-STD-167 as outlined above. Test frequency ranges were curtailed when it was felt that the chock pads had been exposed to severe environment, and that approaching a resonance peak more closely would cause operational problems with the vibration machine. Endurance tests were also sometimes conducted at frequencies lower than those reached in the variable frequency segment

* This was done after all shock and vibration testing had been completed in order to avoid damaging the fit between the chock pads and their mating surfaces.

in order to ease the burden on the vibration machine. The Variable Frequency test was conducted controlling the excursion of the test table measured in its nominal horizontal direction to the specified values. Early in the test, it was found that the hold-down bolt had loosened. They were retorqued, and again loosened after a short time. They were then fitted with lock-washers* and retorqued, after which they maintained torque for the remained of the testing. The Variable Frequency test was then continued up to a frequency of 22 Hz, where the TR was 34:1.

Horizontal 90° Direction - Endurance

The Endurance test was conducted at 17 Hz. It was noted that during the course of the two-hour test, the TR increased from an initial value of 6.2:1 to a final 7.3:1. Following the test, hold-down bolt torque was checked, but no indication of loosening could be found.

Horizontal 45° Direction - Exploratory

The pattern of behavior found in this test was similar to that found in the Horizontal 90° direction. At broad peak in TR was found to start at 6 Hz, increasing more and more rapidly as the frequency increased. At 21 Hz, TR had reached 10:1, and the test was halted.

Horizontal 45° Direction - Varible Frequency

As would be anticipated, this test produced action similar to that observed for the same test in the other horizontal direction, but with slightly different numbers involved. The test was conducted up to 20 Hz, TR 9:1.

Horizontal 45° Direction - Endurance

The endurance test was conducted at 19 Hz. Here too the TR was found to increase as the test proceeded, in this case from 4:1 to 4:5.1. Again, no loosening of the hold-down bolts could be detected.

Post-Vibration Test Inspection

After completion of the vibration tests, Test Structure No. 1 was again disassembled and the chock pads inspected and photographed

*Lock-washers were normally not recommeded, as they may present a "flexibile-foundation" effect to the hold-down bolts, leading to higher dynamic stresses than they would otherwise encounter, and possibly leading to permanent stretch of the bolts during shock tests.

(Figure 9). No signs of damage or gross abrasion were found. The only notable change in appearance following the test was the appearance of a superficial stain on the upper surfaces, and to a lesser degree in the lower surfaces of the chock pads. This may indicate a transfer of surface material (scale, paint, etc.) from the mounting ring and mounting plate to the chock pads and would presumably indicate working between mating surfaces.

Shock Tests of Test Structure No. 1

Shock tests were conducted on the Navy Class HI Shock Machine for Mediumweight Equipment (MWSM) in accordance with the requirements of MIL-S-901C (Ref. 4). The MWSM and its shock characteristics are described in Ref. 5; basically, the MWSM consists of a 5000 lb. anvil table to which the test item is attached by a flexible mounting arrangement and which is struck from below by a 3000 lb. swinging hammer. The flexible mounting arrangement consists of a set of 4 in. channel members supported by base rails attached to the anvil table. The number of channels used is fixed by the weight of the test item and the geometry of its mounting base, and results in a mass-spring-mass fundamental frequency in the vicinity of 65 Hz. The height of the hammer drop is fixed by the total weight attached to the anvil-table. After being struck by the hammer, the anvil-table is allowed to rise freely for a distance of either 3 in. or 1 1/2 in. After traveling this distance, the motion of the anvil-table is abruptly arrested by limiting stops, and it drops back to its initial position under the influence of gravity and whatever rebound velocity it may have. The test procedure of Ref. 4 calls for two test segments of three blows each. The first segment has the test item mounted in its normal vertical orientation, the second has it mounted so as to incline it at an angle of 30° from the vertical in either one or two axes. For single axis inclination, the base rails are replaced by a set whose mounting surfaces are inclined at 30° angle and the test item is attached using the same mounting channels as for the vertical orientation. For two-axis inclination, a separate fixture, the 30° - 30° Corner Bulkhead, is used and the mounting channels are eliminated. For each test segment, vertical and inclined, a series of three blows are delivered. The first is given with a height of hammer drop roughly half that which produces shock of full test severity, and serves an exploratory function. For the second blow, the hammer is dropped from the height required for full test severity, and (as for the first blow) the anvil-table is set for 3 in. free travel. For the third blow, the hammer is dropped from the same height, but the anvil-table travel is restricted to 1 1/2 in. This has the following purpose. As the anvil-table, test item and mounting-channel arrangement is rising freely, it oscillates as a mass-spring-mass system (to take the simplest model of the real system). When the mass representing the anvil-table suddenly runs into the stops, a secondary shock is introduced into the system, and the severity of its effects on the test item will depend on at what phase of the basic oscillation it is introduced. Since the mounting-channel arrangement is not fine-tuned to an individual test item

(i.e., items having weight and mounting dimensions within certain ranges all have the same mounting-channel arrangeements), the frequency of the basic oscillation and thus its phase at the time of secondary shock introduction may vary substantially for rather unimportant variations in the structure of similar test items. Having two tables travels helps to prevent discrimination against a given test item on this basis. If the effects of secondary shock are unusually severe with one travel, they will tend to be correspondingly moderate with the other.

The purpose of the second segment of the test, where the test item is inclined to the vertical, is simply to introduce some shock into the horizontal axes of the item. While this procedure reduces the shock along the vertical axis, the heights of hammer drop are not increased to compensate, but only as specified for the increased weight on the anvil-table.

Vertical Shock

The Test Structure No. 1 assembly is shown arranged for vertical shock in Fig. 10. The mounting channel arrangement (two pairs of standard channels, equivalent to two car-building channels) is that specified for a test item of weight equal to that of the Test Structure mounting plate assembly and having a mounting bolt separation equal to the space between the bolts used to fasten the mounting plate to the mounting channels.

Blow 1 - 1 ft. Drop, 2 in. Travel

No apparent effect on the chock pads. The four (mounting ring) hold-down bolts passing through Pad 1 and the adjacent ends of Pads 5 and 6 loosened slightly, and were retorqued. These four bolts were the ones closest to the mounting channels.

Blow 2 - 2 ft. Drop, 3 in. Travel

No apparent effect on the chock pads. The same four bolts again loosened slightly, and were retorqued.

Blow 3 - 2 ft. Drop, 1 1/2 in. Travel

No apparent effect on the chock pads. Once more, the same four bolts loosened slightly and were retorqued.

Inclined Shock

The Test Structure No. 1 assembly was next installed in the 30° - 30° Corner Bulkhead as shown in Fig. 11. It was oriented so that Pad 2 was closest to the corner.

Blow 4, 1 3/4 ft. Drop, 3 in. Travel

About two-thirds of the overpour region of Pad 3 spalled off (Fig. 12), but without visible damage to the load-bearing area.

Blow 5 - 2 3/4 ft. Drop, 3 in. Travel

The remainder of the overpour volume of Pad 3 broke off (Fig. 13), still with no apparent damage to the load-bearing area.

Blow 6 - 2 3/4 ft. Drop, 1 1/2 in. Travel

No apparent effect on the chock pads.

Post-Shock Test Inspection

The test structure assembly was next disassembled and the chock pads inspected. A crack was found in Pad 6 (diametrically opposite Pad 2) between the overpour region and the load-bearing area, apparently and early stage of the cracking process which had led to the spalling of Pad 3.

Extra Blows

The test structure assembly was then reinstalled in the 30° - 30° corner Bulkhead with the hold-down bolts (mounting ring to mounting plate) torqued to 8 ft-lb. This was the torque required to hold the lockwashers in position without closing them. Blows 5 and 6 were then repeated.

Blow 7 - 2 3/4 ft. Drop, 3 in. Travel

A small fragment of Pad 3 spalled off under the outer edge of the mounting ring. The crack previously noted in Pad 6 progressed completely through, but without spalling off.

Blow 8 - 2 3/4 ft. Drop, 1 1/2 in. Travel

No apparent effect on the chock pads.

Final Inspection

The test structure assembly was then taken apart for the last time. Except for the cracking and spalling noted above, the condition of the chock pads seemed unchanged by the shock test. Figure 14 shows the chock pads in their final state, with the three fragments which had successively spalled off Pad. 3. Figure 15 shows the crack in Pad 6, and probably indicates how the cracking of Pad 3 progressed after initiation at the high-stress zone at the corner of the mounting ring.

Vibration Test of Test Structure No. 2

The second test structure assembly was then prepared (the hold-down bolts being fitted with lock-washers) and mounted on the test table of the NRL 5000 lb Reaction-Drive Vibration Test Machine. Figure 16 shows the assembly oriented for the Horizontal 90° Direction, Figure 17 for Horizontal 45°. The vibration test was as described by MIL-STD-167-1, Type I.

Vertical Direction - Exploratory

Principal resonance was found at 25 Hz, TR 1.3:1, and a secondary resonance at 47 Hz, 1.2:1. No significant difference could be found between the amplitude of motion of the mounting ring and that of the mounting plate.

Vertical Direction - Variable Frequency

The test was conducted over the frequency range of 4-47 Hz. A slight increase in TR (1.2:1) started at 25 Hz and slowly increased with increasing frequency, peaking at a value of 2:1 at 47 Hz. No effect on the chock pads could be observed.

Vertical Direction - Endurance

The test was conducted at 33 Hz, TR 1.25:1. No effect on the chock pads could be observed.

Horizontal 90° Direction - Exploratory

A first resonance was found at 14 Hz, TR 5:1, and a complex, bimodal response in the vicinity of 27 Hz. One peak, slightly below 27 Hz, appeared to involve rocking of the test structure on the chock pads, and showed TR 10:1. The other peak, slightly above 27 Hz, seemed to involve a rocking more of the entire test assembly and test table as a unit, with TR 6:1. The Exploratory test was terminated at this point.

Horizontal 90° Direction - Variable Frequency

At 15 Hz, TR increased to 1.1:1, and continued to increase with frequency, reaching 10.5:1 at 23.5 Hz. The Variable Frequency test was terminated at this point. No effect on the chock pads could be detected.

Horizontal 90° Direction - Endurance

The Endurance test was conducted at 23 Hz, TR 6:1. No effect on the chock pads could be detected.

Horizontal 45° Direction - Exploratory

A behavior was found similar to that found in the Horizontal 90° Direction. A slight peak of response was found at 14 Hz, and a large peak associated with complex motions at about 23 Hz.

Horizontal 45° Direction - Variable Frequency

The TR was found to increase starting at a frequency of 15 Hz. Motions also became more complex above this frequency, with varying contributions from rocking and rotation of both the test structure and the test structure/test table combination. The frequency range was restricted to 21 Hz, TR 2.5:1. No effect on the chock pads was apparent.

Horizontal 45° Direction - Endurance

The Endurance test was conducted at 20 Hz, TR 2.8:1. Note that the TR was larger than that noted above for 21 Hz. This is due to the somewhat restrictive definition of the procedure used to determine TR*. The overall motion was in fact considerably less violent. No effect on the chock pads could be detected.

Post-Vibration Test Inspection

Figure 18 shows the chock pads following completion of the vibration test. Little or no change from the original condition could be found (compare Figure 6), save for slight surface discoloration in spots. The general surface discoloration noted for Test Structure No. 1 was absent.

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* As defined above, the TR between a point on a test item and the test table (or between two points on the item) is the ratio of the amplitudes of motion along the specified axis, without regard to phase, spectral purity or the possible presence of motion other than linear motions along the specified axis. This quantity is simple and usually informative and easy to interpret in terms of the test item's dynamical behavior. In some cases, such as the present one, the off-axis motion are sufficiently pronounced to limit the amount of useful information which can be conveyed by the simple TR. In addition, the practical method used to measure the motions in order to calculate TR is to attach pickups oriented along the specified axis when the system is at rest. When the motion involves considerable rotations, the true axis of measurement changes as a function of the motion, so that the measured amplitude is a mélange of the various elemental motions of which the total system is composed. Under such conditions, the TR is not a reliable indicator of the overall vigor of the test item's motion.

Shock Test of Test Structure No. 2

The shock test was conducted on the MWSM in accordance with the requirements of MIL-S-901C (Ref. 4).

Vertical Shock

Figure 19 shows the Test Structure No. 2 assembly arranged for Vertical shock. The mounting channels consist of two mixed pairs of channels, equivalent to three car-building channels.

Blow 1 - 1 3/4 ft. Drop, 3 in. Travel

No apparent effect on the chock pads. The hold-down bolts in Pads 0, 1, 4, 5 and 6 loosened slightly. These bolts were nearest the mounting channels.

Blow 2 - 2 1/4 ft. Drop, 3 in. Travel

No apparent effect on the chock pads. The same bolts loosened slightly, and were again retorqued.

Blow 3 - 2 1/4 ft. Drop, 1 1/2 in. Travel

No apparent effect on the chock pads. No loosening of the hold-down bolts was found.

Inclined Shock

Figure 20 shows the test structure assembly mounted in the 30° - 30° Corner Bulkhead. The joint between Pads 4 and 5 was closest to the corner.

Blow 4 - 2 1/4 ft. Drop, 3 in. Travel

No apparent effect on the chock pads.

Blow 5 - 3 1/2 ft. Drop, 3 in. Travel

No apparent effect on the chock pads.

Blow 6 - 3 1/2 ft. Drop, 1 1/2 in. Travel

No apparent effect on the chock pads.

Post-Shock Test Inspection

The test structure assembly was disassembled and the chock pads inspected and photographed (Fig. 21). No change in their condition could be seen.

Extra Blows

The test structure assembly was reassembled with the hold-down bolts torqued to 10 ft-lb, and installed in the 30° - 30° Corner Bulkhead with Pad 8 closest to the corner.

Blow 7 - 3 1/2 ft. Drop, 3 in. Travel

The corner of the overpour region of Pad 8 adjacent to Pad 0 developed a slightly chewed appearance. No other changes could be seen.

Blow 8 - 3 1/2 ft. Drop, 1 1/2 in. Travel

The corner of Pad 8 affected by Blow 7 chipped off. No other effects could be detected.

Blow 9 - 3 1/2 ft. Drop, 3 in. Travel

Prior to this blow, the hold-down bolts were loosened completely. No effect on the chock pads could be detected.

Final Inspection

Figure 22 shows the chock pads after the completion of testing. Save for the chipped corner of Pad 8 and some spots of surface discoloration, there appeared to be no change in their condition since the initial post-curing inspection.

Discussion of Test Results

The test described in this report did not produce any effect on the epoxy chock pads which would interfere with their effectiveness as chocks. Test temperature was found to influence Izod impact strength slightly, and compressive strength considerably, but still not to such a degree that problems in service would be anticipated in this regard. Vibration tests caused little or no abrasion or deformation, although the steady increase of the TR of Test Structure No. 1 during the horizontal Endurance runs may indicate some tendency to creep. However, no loosening of the hold-down bolts could be found, and the increase in TR did not occur during tests of Test Structure No. 2. Shock tests cause some minor cracking and spalling which did not extend into load-bearing areas.

A major consideration not specifically addressed by these tests is whether the presence of chocks (of any description) seriously enhance the severity of the dynamic environments imposed on the equipment mounted on them. Observations during the vibration tests indicate that the presence of the chocks did influence the motions of the test structures, but the complexity of the dynamics of the structures makes it difficult to evaluate the nature or magnitude of the influence. For

vibration in the vertical direction, where the situation was relatively simple, the presence of the chocks seemed to have no significant effect. At frequencies higher than those employed here it is possible that some magnification of motion could be produced, but it would also be reasonable to expect that for some range of frequencies the chocking material would be dissipative. For horizontal motion it would be prudent to consider the effects of introducing a spring element (the chocks) between the mounted equipment and the ship, where the flexibility of the added element might be high relative to those of the equipment and the place where it is mounted. Note that this comment applies to chocks of any description. While the modulus of the epoxy compounds may be much lower than those of metals, the intimacy of fit between mating surfaces and large bearing areas resulting from casting in place could tend to produce comparable total stiffness.

Limitations of Tests

Some potential weaknesses peculiar to epoxy chocking materials were not addressed by the tests reported here. Some of these are listed below.

1. While test temperature seems not to degrade the properties of the epoxy material significantly, the effect of prolonged exposure to extreme temperatures might be more serious.

2. For these tests, the manufacturer's recommendations for preparation, mixing, curing, etc. were followed. Departures from these recommendations may result in a product of less desirable properties.

3. The structural components adjacent to the chock pads as tested (the mounting ring and mounting-plate) were relatively rigid. A more flexible situation might permit enough bending of the pads to cause widespread multiple cracking with possible escape of chock material fragments.

Conclusion

Chocks formed from a commercial epoxy chocking compound have been exposed to shock and vibration environments specified for acceptance testing of shipboard equipment without significant degradation. Indications are that test temperature has a small effect on impact strength, and a large effect on compressive strength, but not enough to cause problems in service. Chocks of any description represent an additional spring element introduced between the mounted item and ship structure, and may have an effect on the motions undergone by the mounted item as a result of shipboard shock and vibration environments. Unexplored were the possible effects of improper chock preparation and installation, prolonged exposure to extreme temperatures, and the possibility that use with relatively flexible mounted items and/or mounting locations could allow enough bending of the chocks to impair their integrity.

References

1. ASTM D 695-69, "Standard Test Method for Compressive Properties of Rigid Plastics," American Society for Testing and Materials, 1916 Race St., Philadelphia, PA 19103.

2. ASTM D 256-73, "Standard Test Methods for Impact Resistance of Plastics and Electrical Insulating Materials," American Society for Testing and Materials, 1916 Race St., Philadelphia, PA 19103.

3. MIL-STD-167-1 (SHIPS), "Military Standard Mechanical Vibrations of Shipboard Equipment (Type I - Environmental and Type II - Internally Excited)," NAVSEC 6124, May 1974.

4. MIL-S-901C (NAVY), "Military Specification - Shock Tests, H. I. (High Impact); Shipboard Machinery, Equipment and Systems, Requirements for," BUSHIPS, 15 January 1963.

5. E. W. Clements, "Shipboard Shock and Navy Devices for its Simulation," NRL Report 7396, 14 July 1972, DDC #AD746,444.

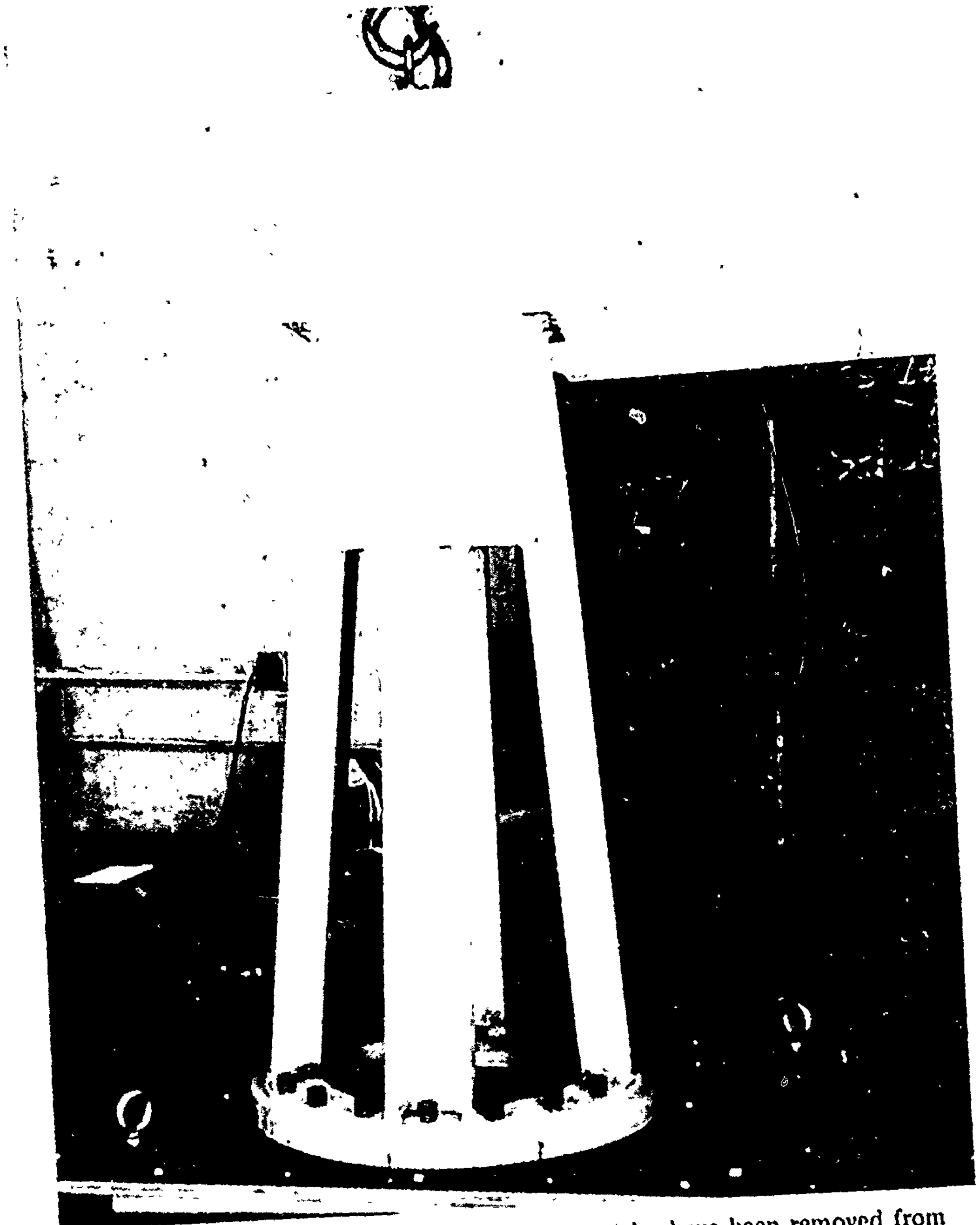

Fig. 1 — Test Structure No. 1. The damming strips have been removed from the cured chocks. Overall height is 47 1/2 in.

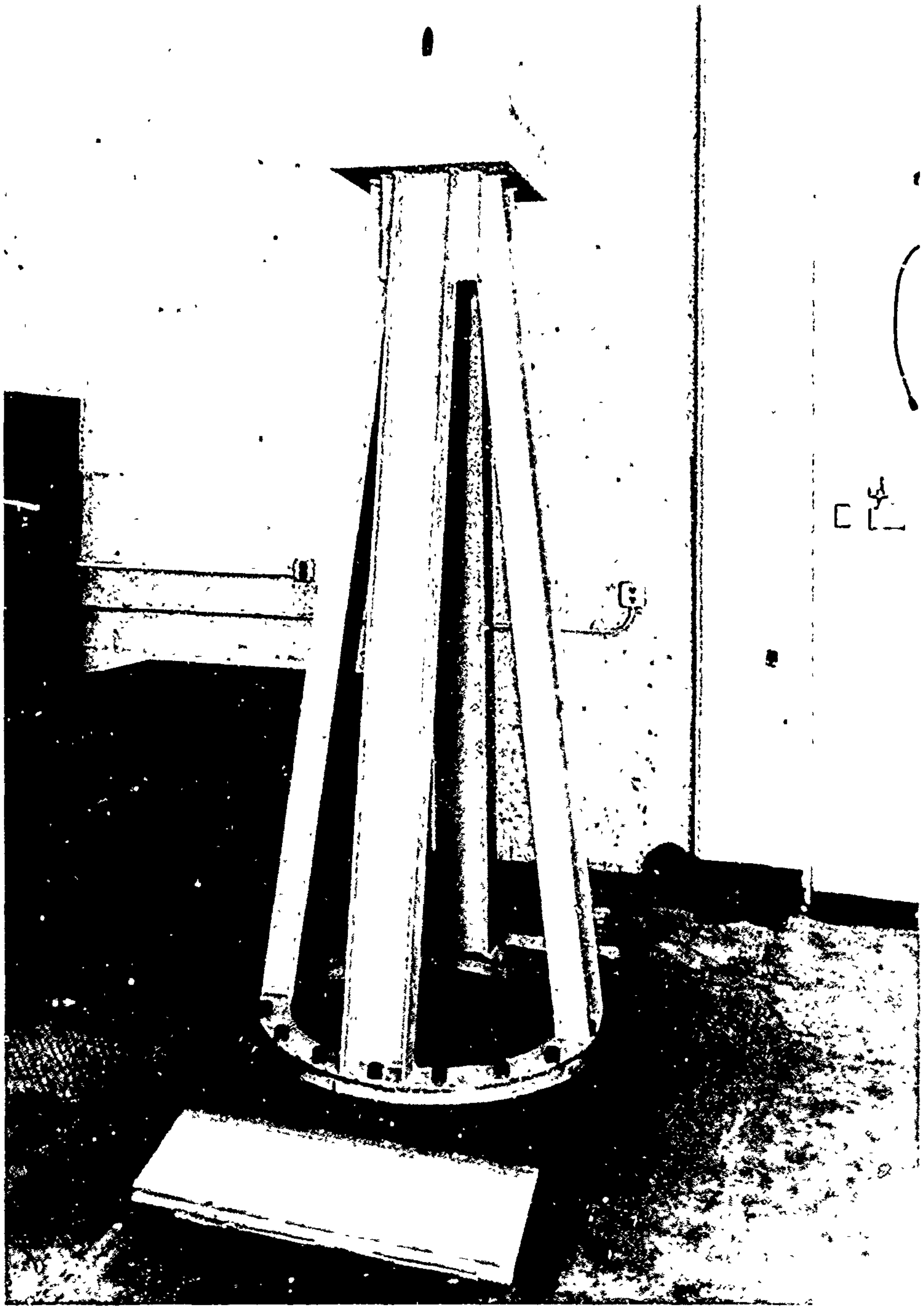

Fig. 2 — Test Structure No. 2 after removal of the damming strips. Overall height is 90 3/4 in.

Fig. 3 — Detail of the mounting ring and chock pads of Test Structure No. 1 before disassembly. Pad 1 is front center.

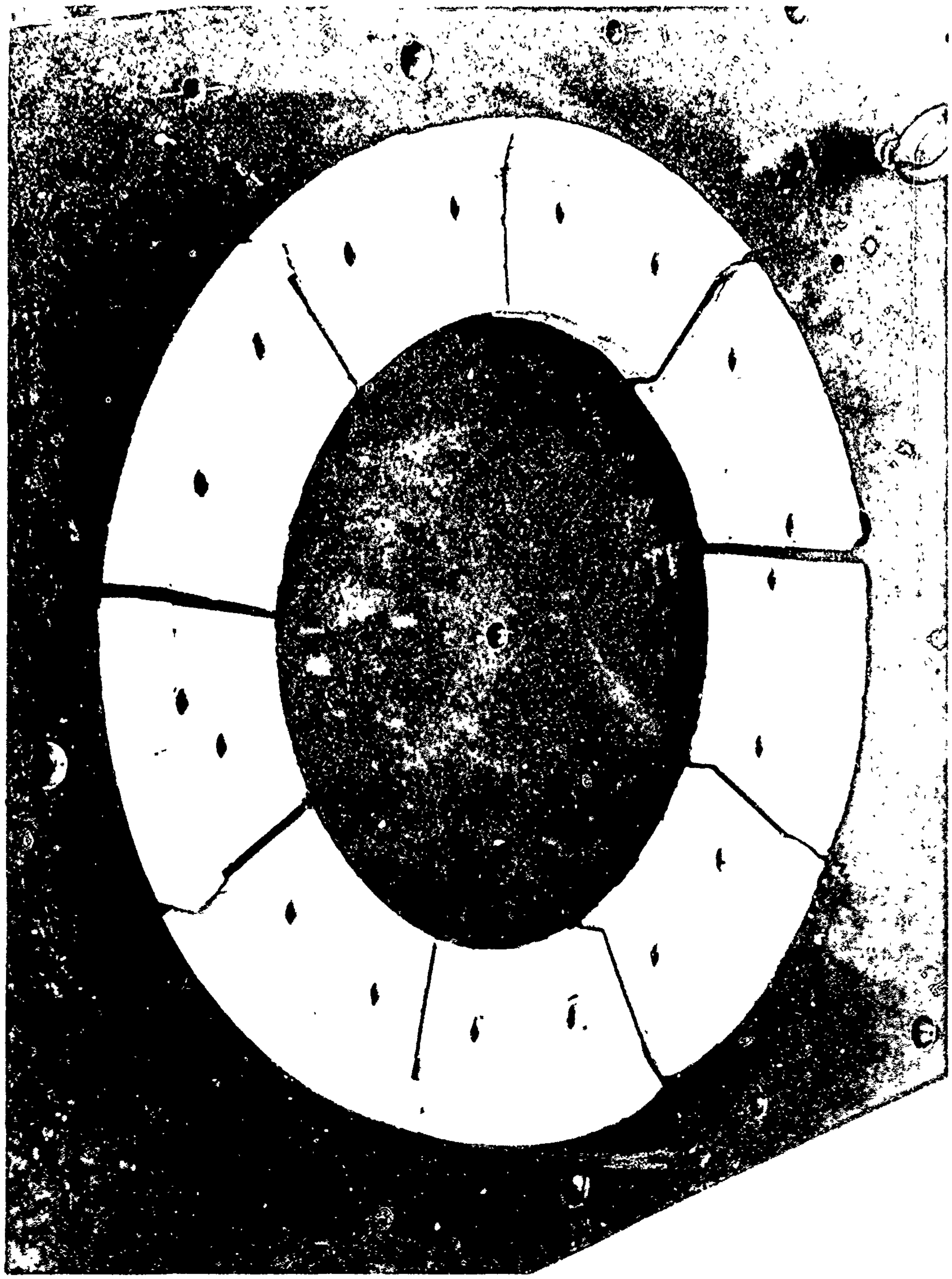

Fig. 4 — Chock pads of Test Structure No. 1 after separation. The continuous ring of overpour was cut with a bandsaw. Note the porous structure and occasional voids, as in Pad 1.

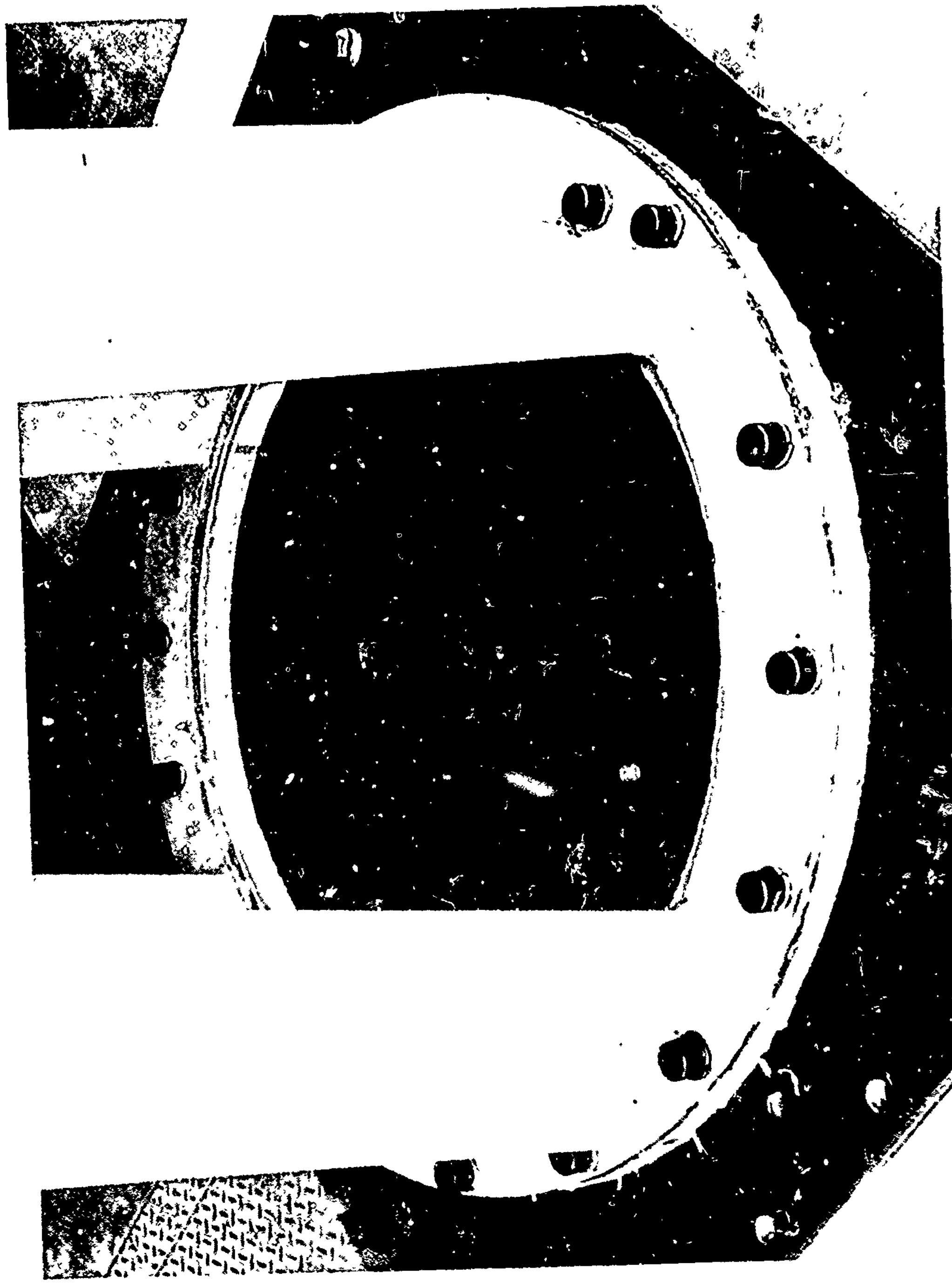

Fig. 5 — Mounting ring and chock pads of Test Structure 2 before disassembly.

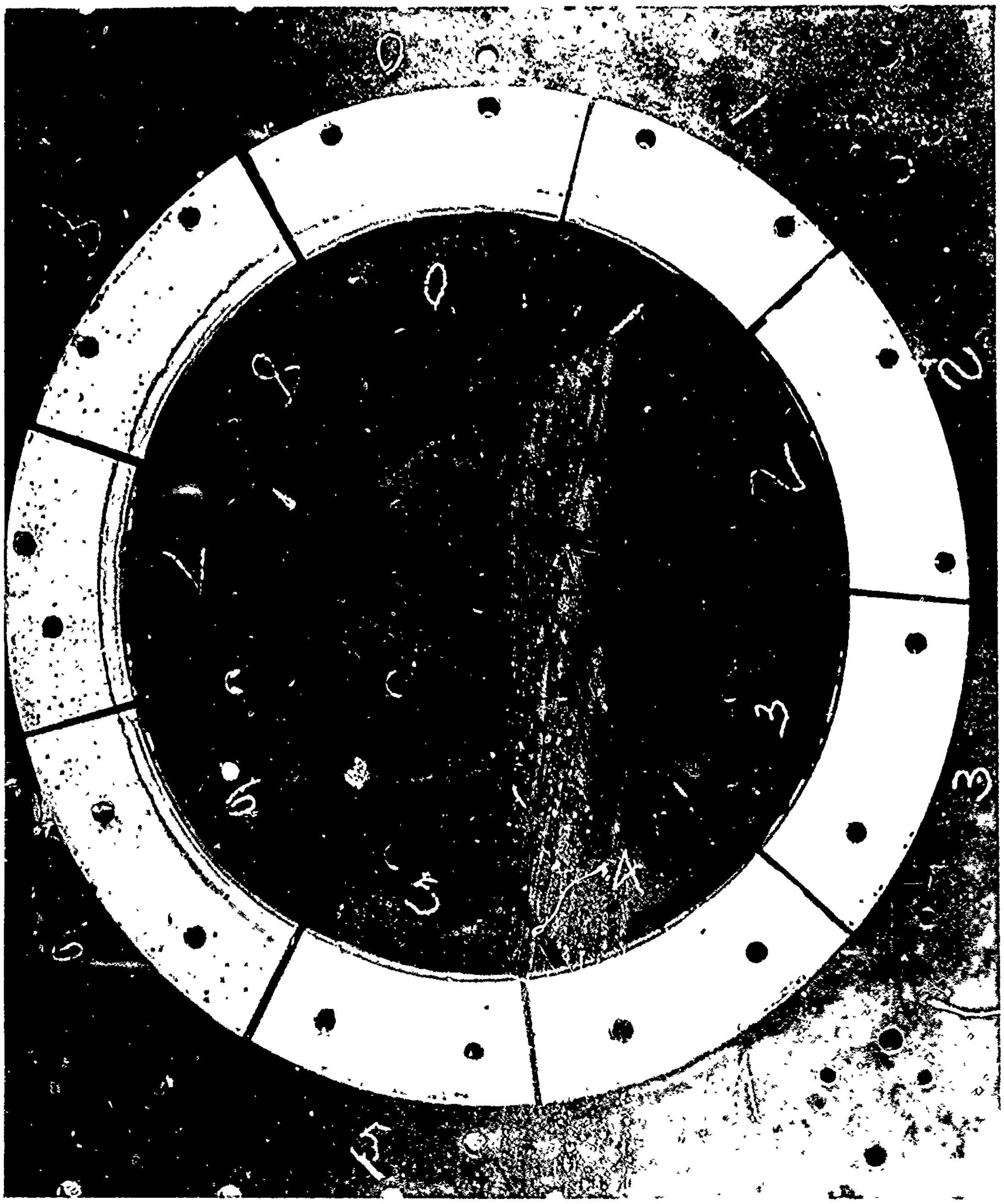

Fig. 6 - Top surface of chock pads of Test Structure No. 2. Porosity and voids are slightly less pronounced than for Test Structure No. 1.

Fig. 7 – Bottom surface of chock pads for Test Structure No. 2.

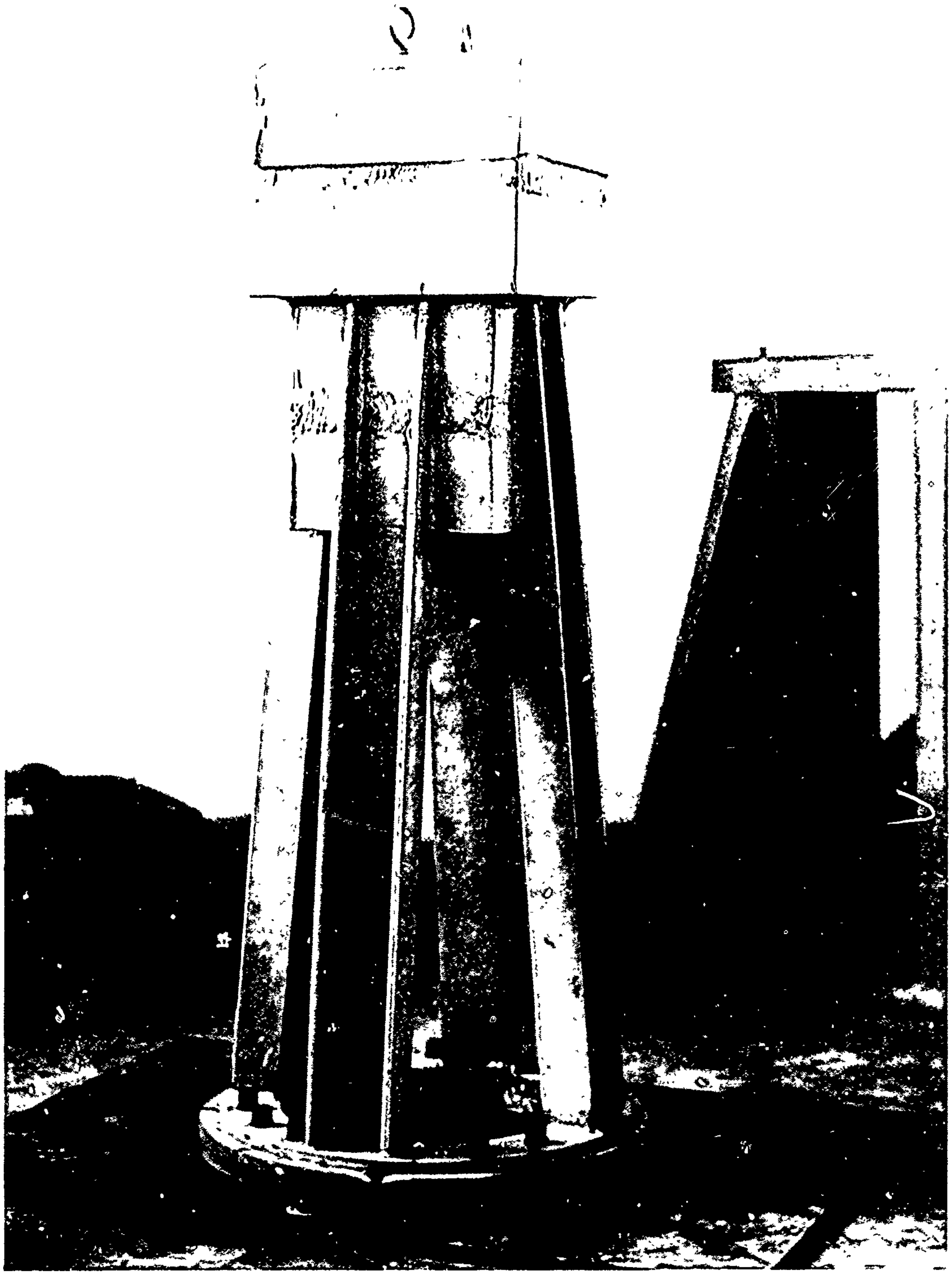

Fig. 8 — Test Structure No. 1 on the NRL 5000 lb Reaction-Drive Vibration Machine. The structure is oriented for vibration in the Horizontal 45° direction, but has not been fastened to the test table of the Vibration Machine.

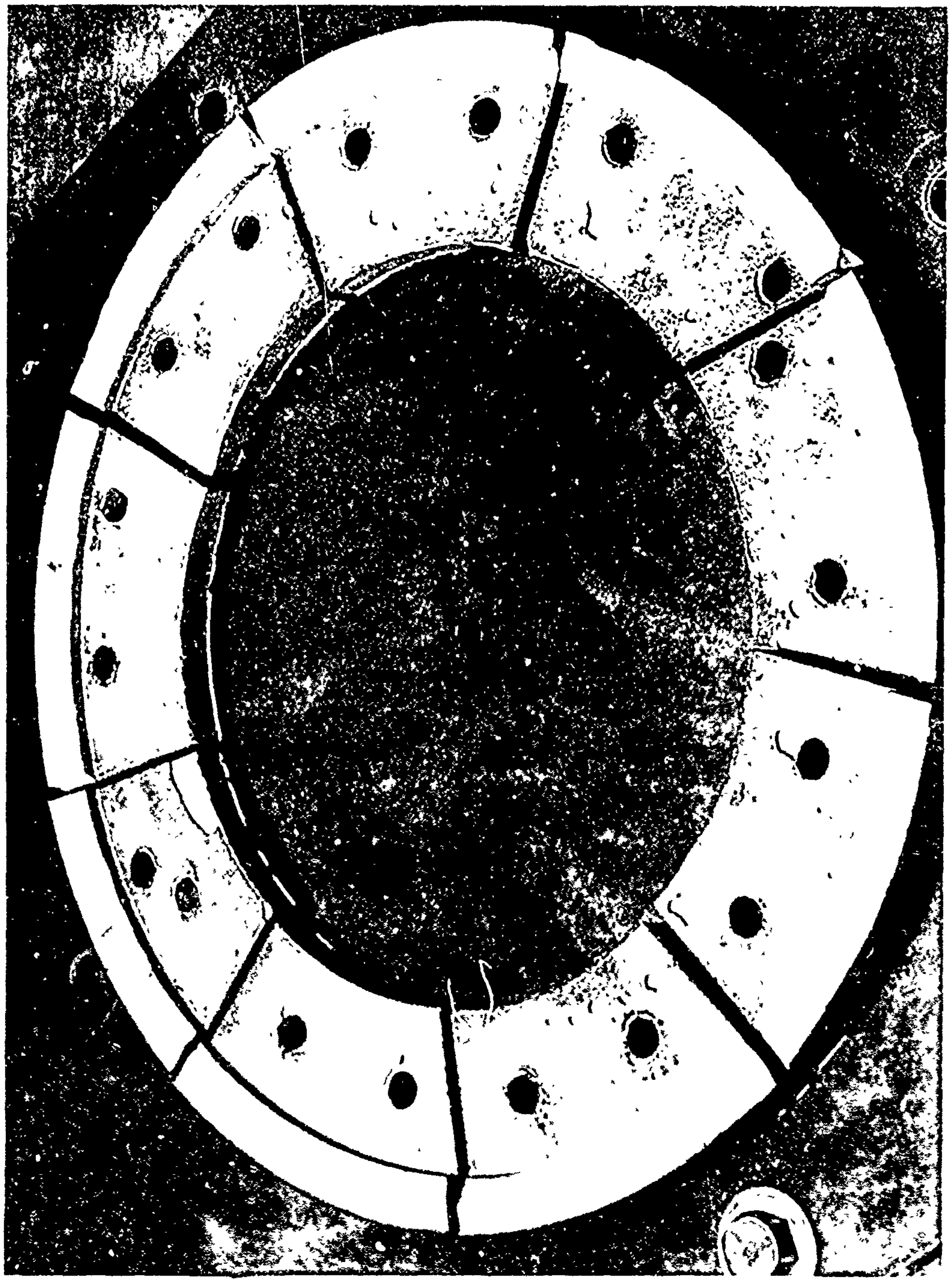

Fig. 9 — Chock pads of Test Structure No. 1 after vibration tests. The only change from Fig. 4 is the addition of a superficial stain which may indicate working between the mating surfaces. No signs of wear or abrasion are noticeable.

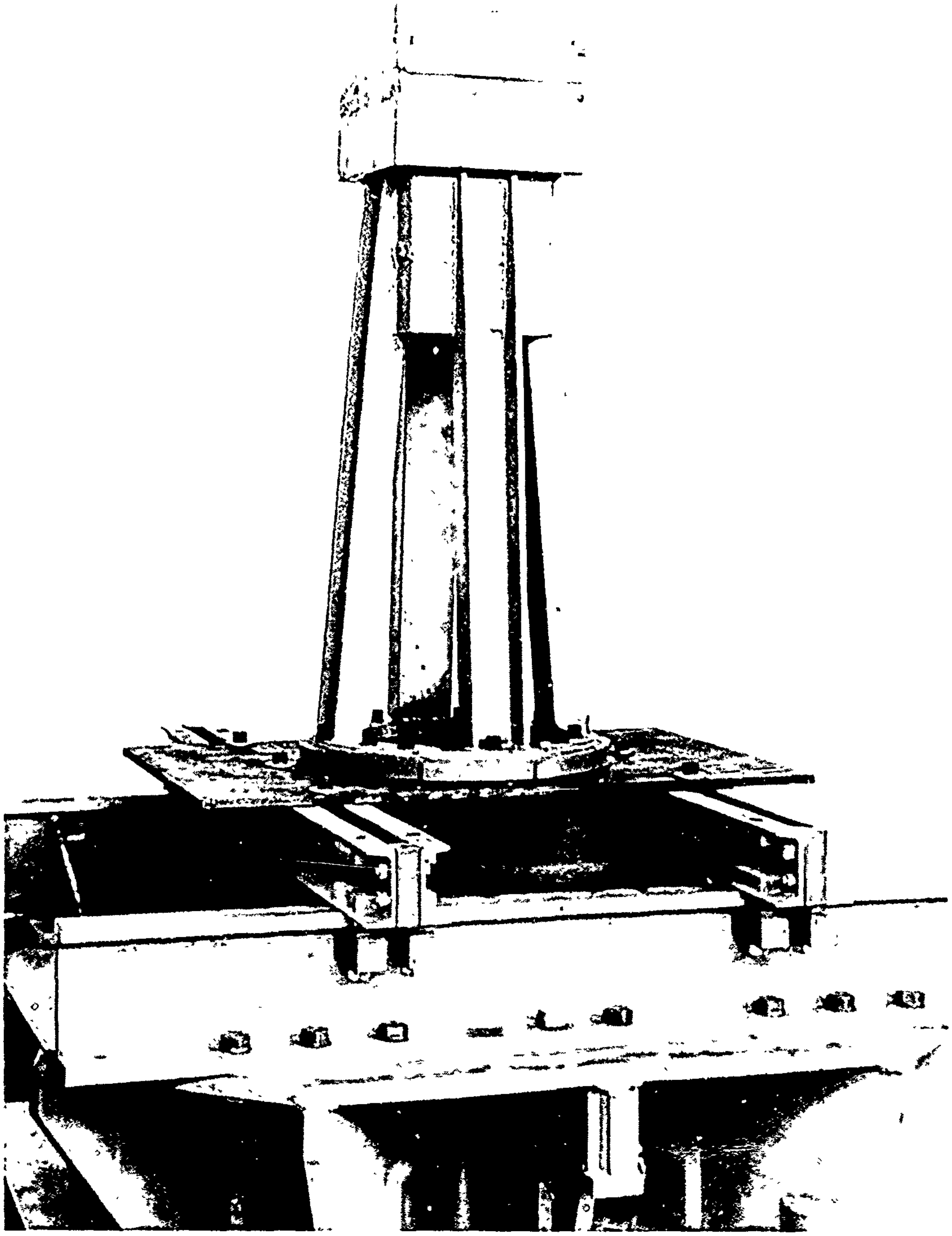

Fig. 10 — Test Structure No. 1 on the Navy HI Shock Machine for Medium-weight Equipments (MWSM), arranged for vertical shock.

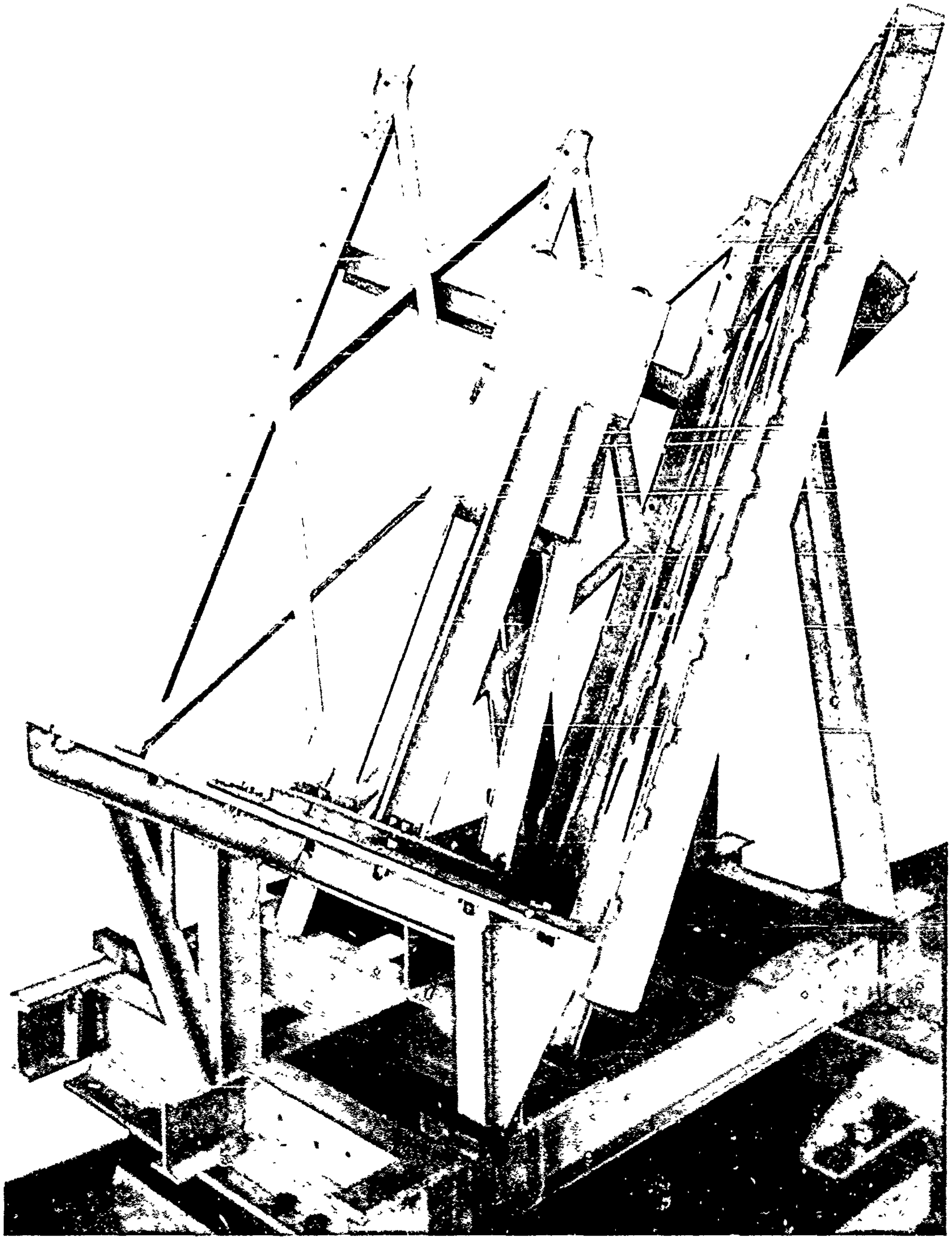

Fig. 11 — Test Structure No. 1 on the MWSM arranged for inclined shock. The assembly is mounted in the 30° - 30° Corner Bulkhead.

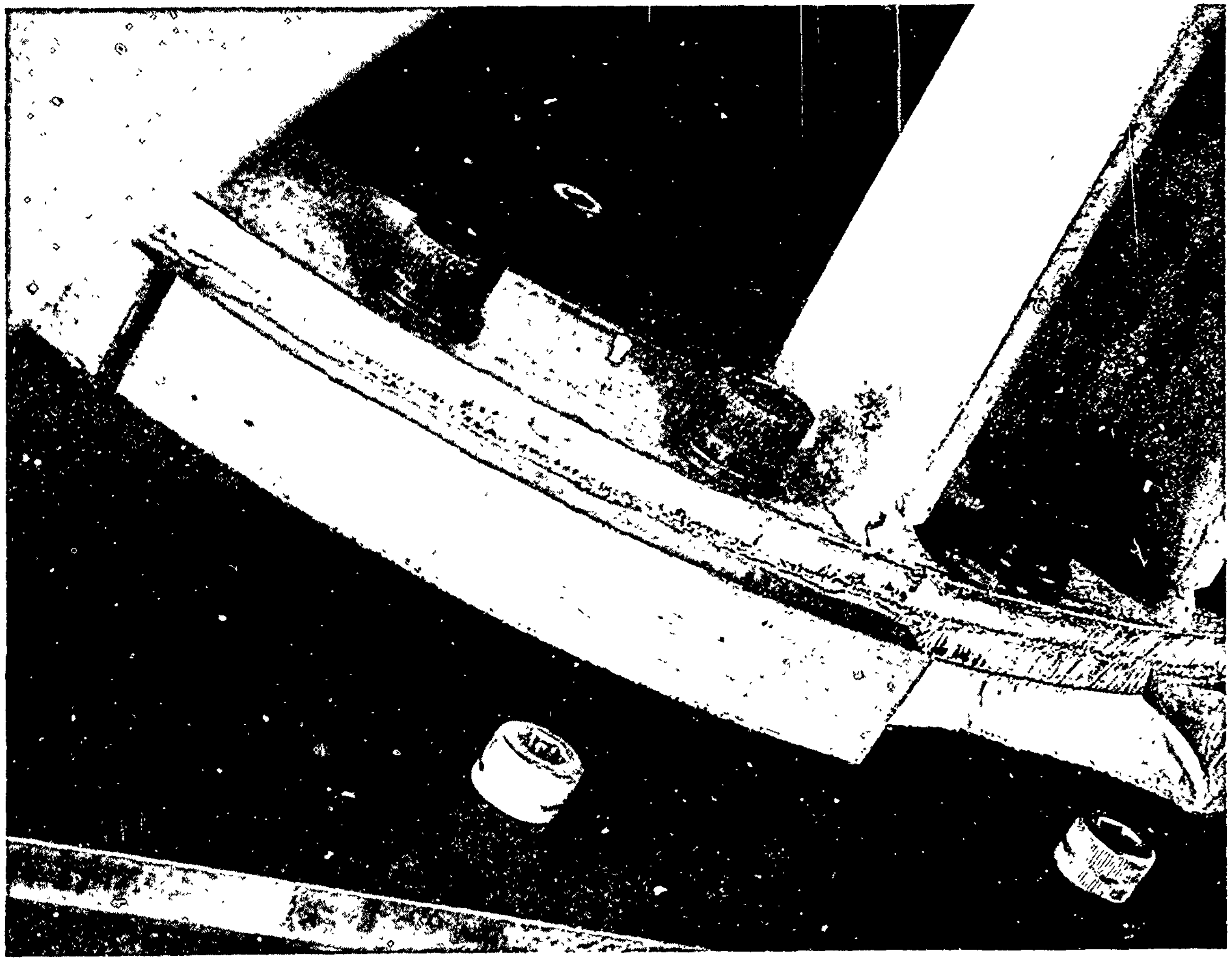

Fig. 12 — Damage to Pad 3 of Test Structure No. 1 caused by Blow 4. A section of the overpour region was spalled off, but the load-bearing area is not significantly affected.

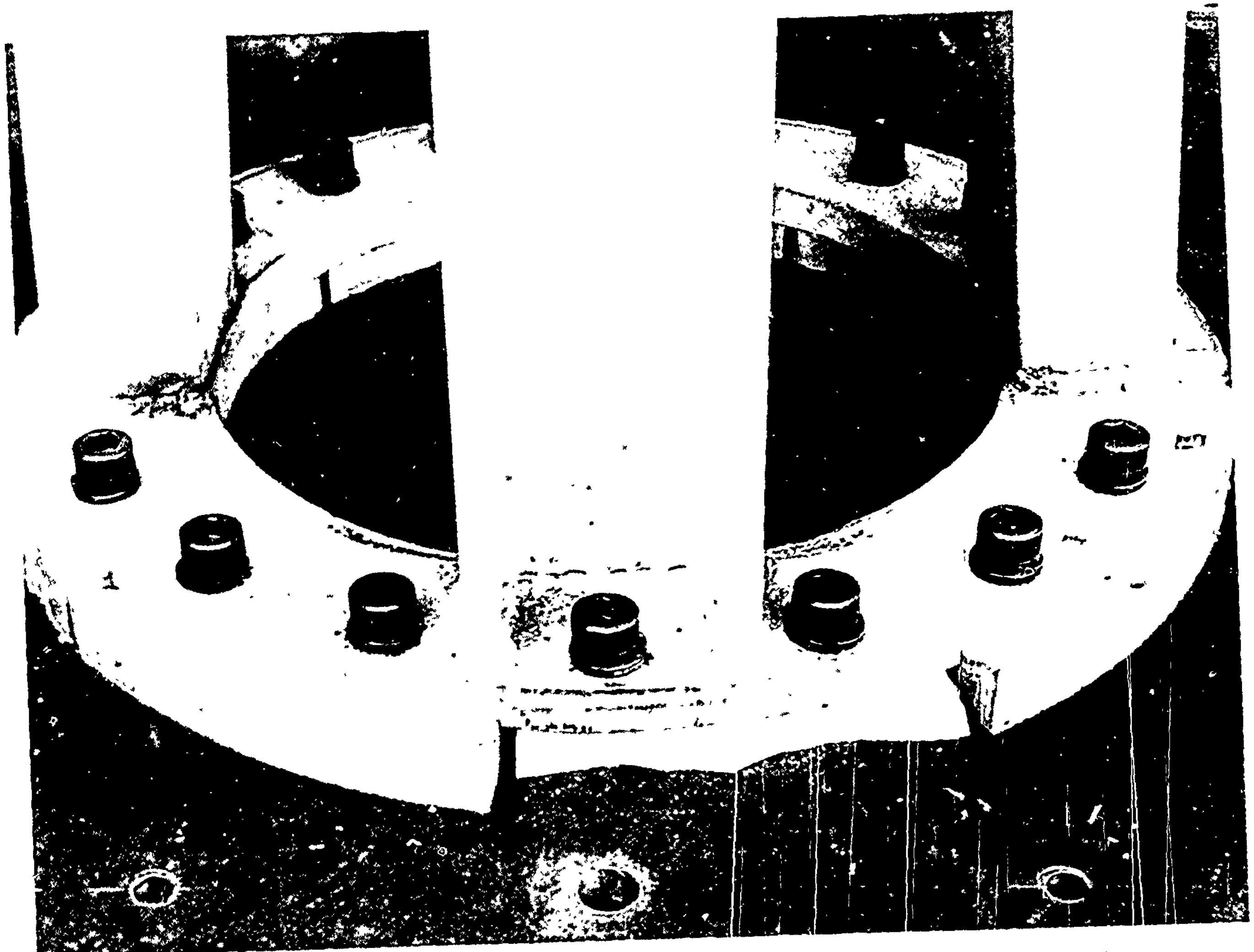

Fig. 13 — Damage to Pad 3 of Test Structure No. 1 due to shock *test*. The rest of the overpour region spalled off during Blow 5, still without significant involvement of the load-bearing area.

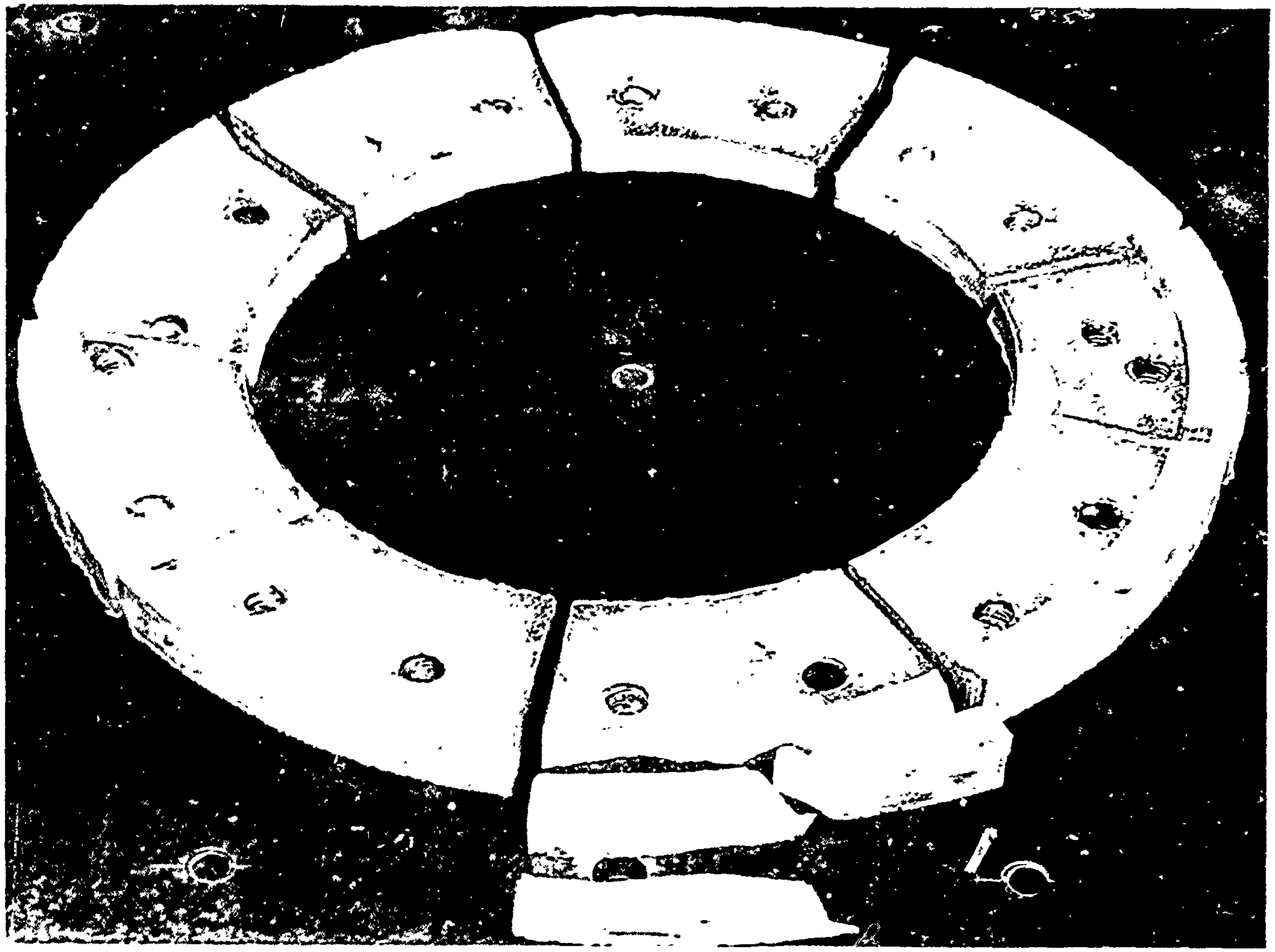

Fig. 14 — Chock pads of Test Structure No. 1 after completion of shock and vibration tests.

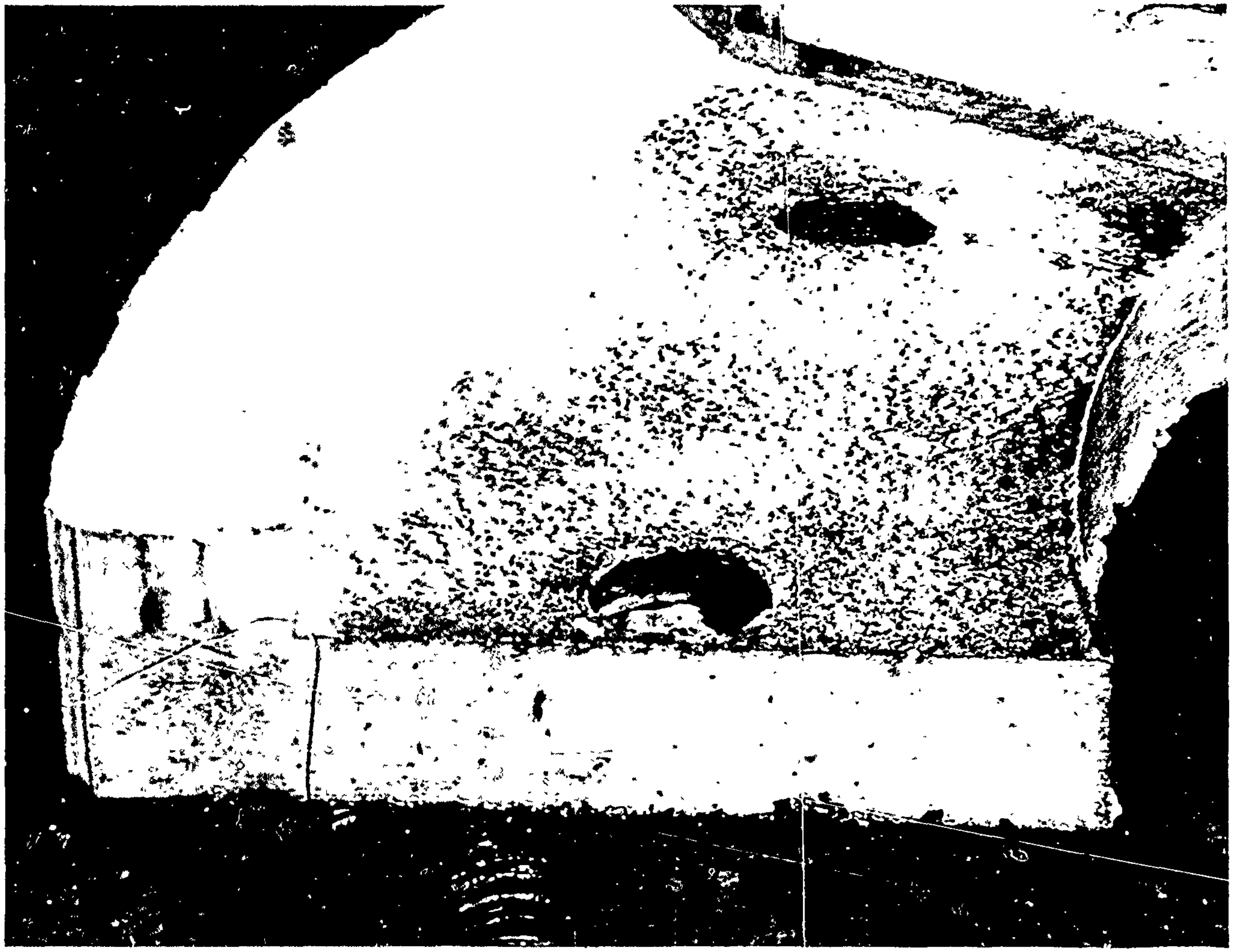

Fig. 15 — Cracks in Pad 6 of Test Structure No. 1 following shock and vibration tests. The pattern of cracking appears to be one which would progress to produce spalling such as occurred in Pad 3.

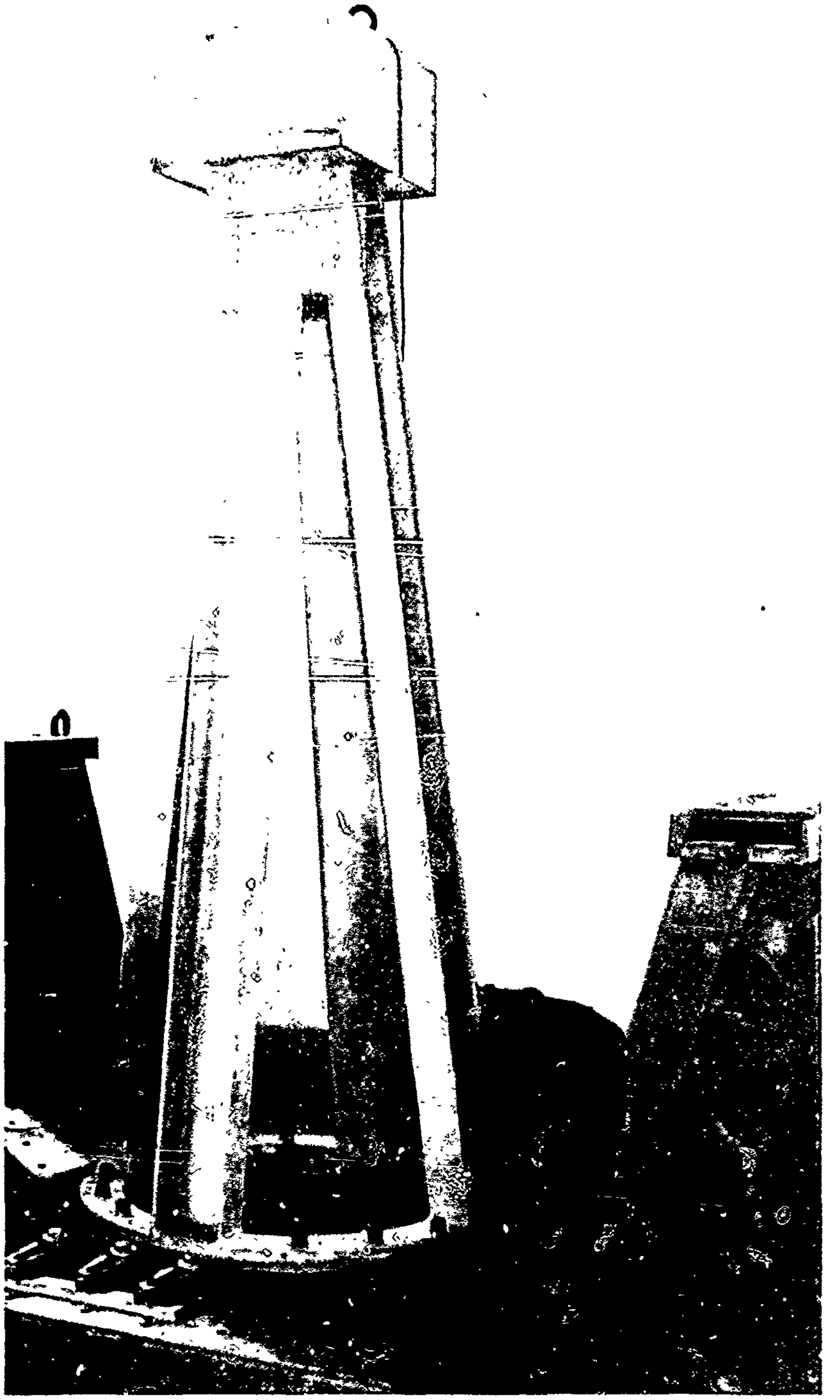

Fig. 16 — Test Structure No. 2 mounted on the vibration machine and oriented for vibration in the Horizontal 90° direction.

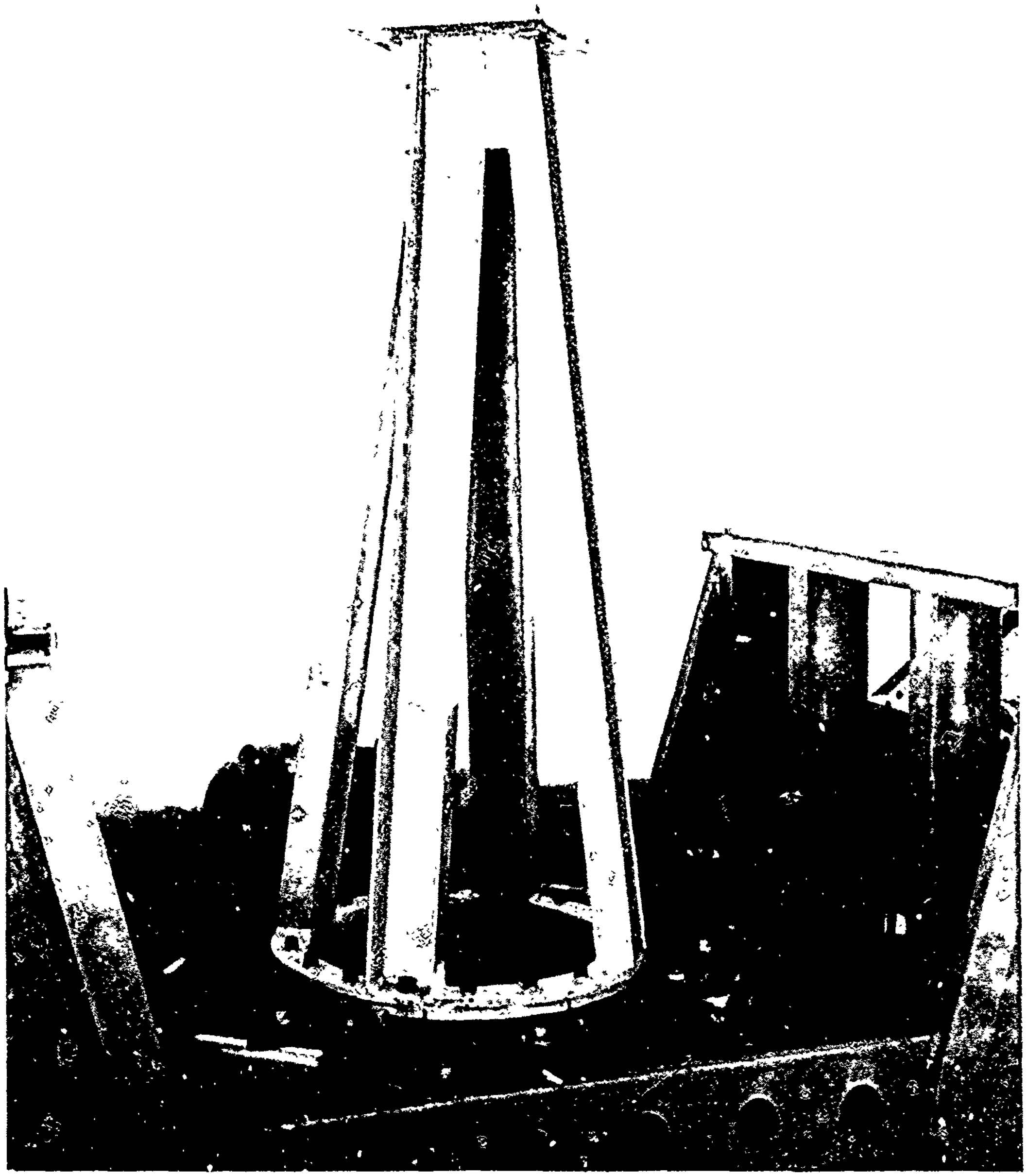

Fig. 17 — Test Structure No. 2 mounted on the vibration machine and oriented for vibration in the Horizontal 45° direction.

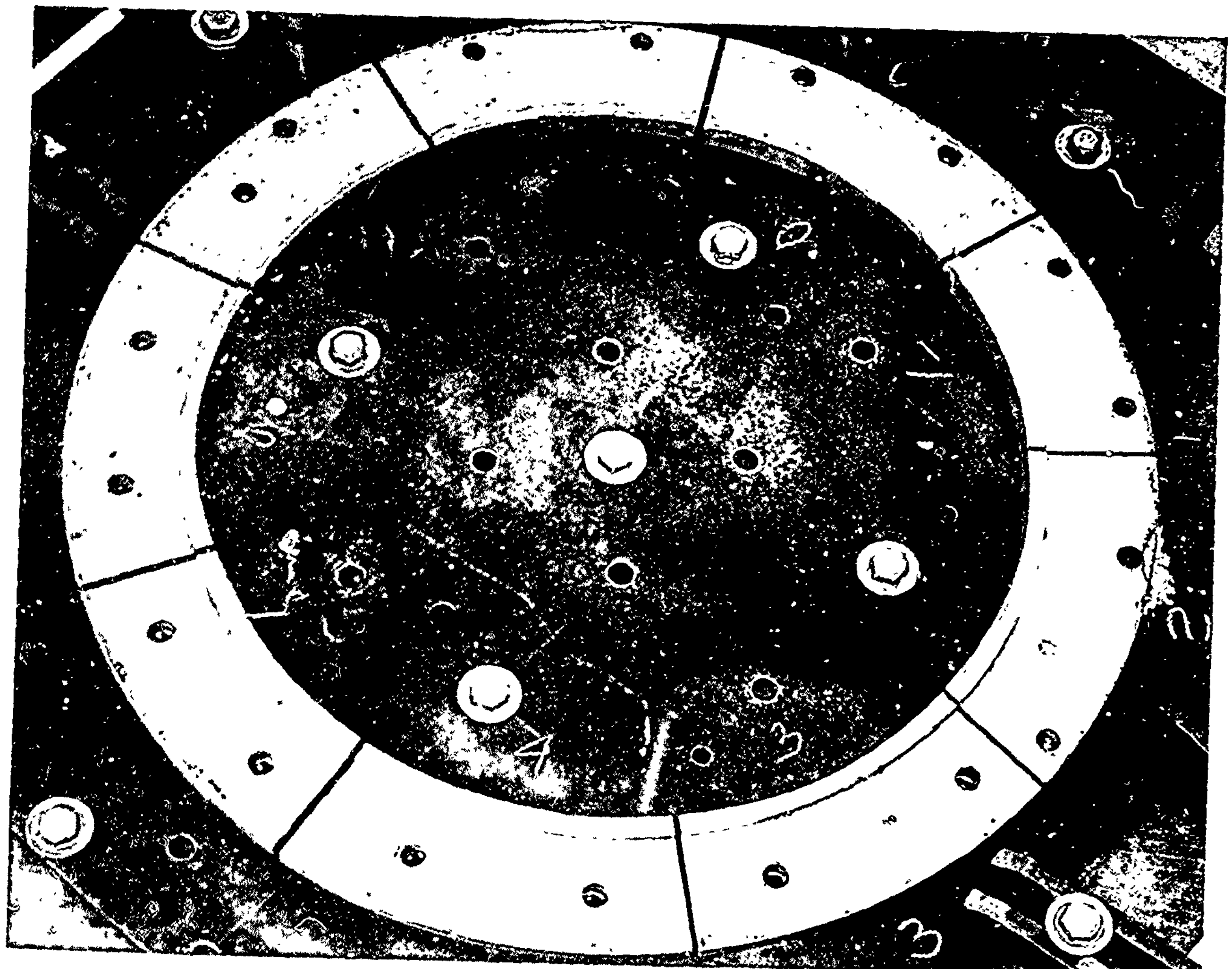

Fig. 18 — Chock pads of Test Structure No. 2 following vibration testing. General surface staining such as that noted with the pads of Test Structure No. 1 is not apparent.

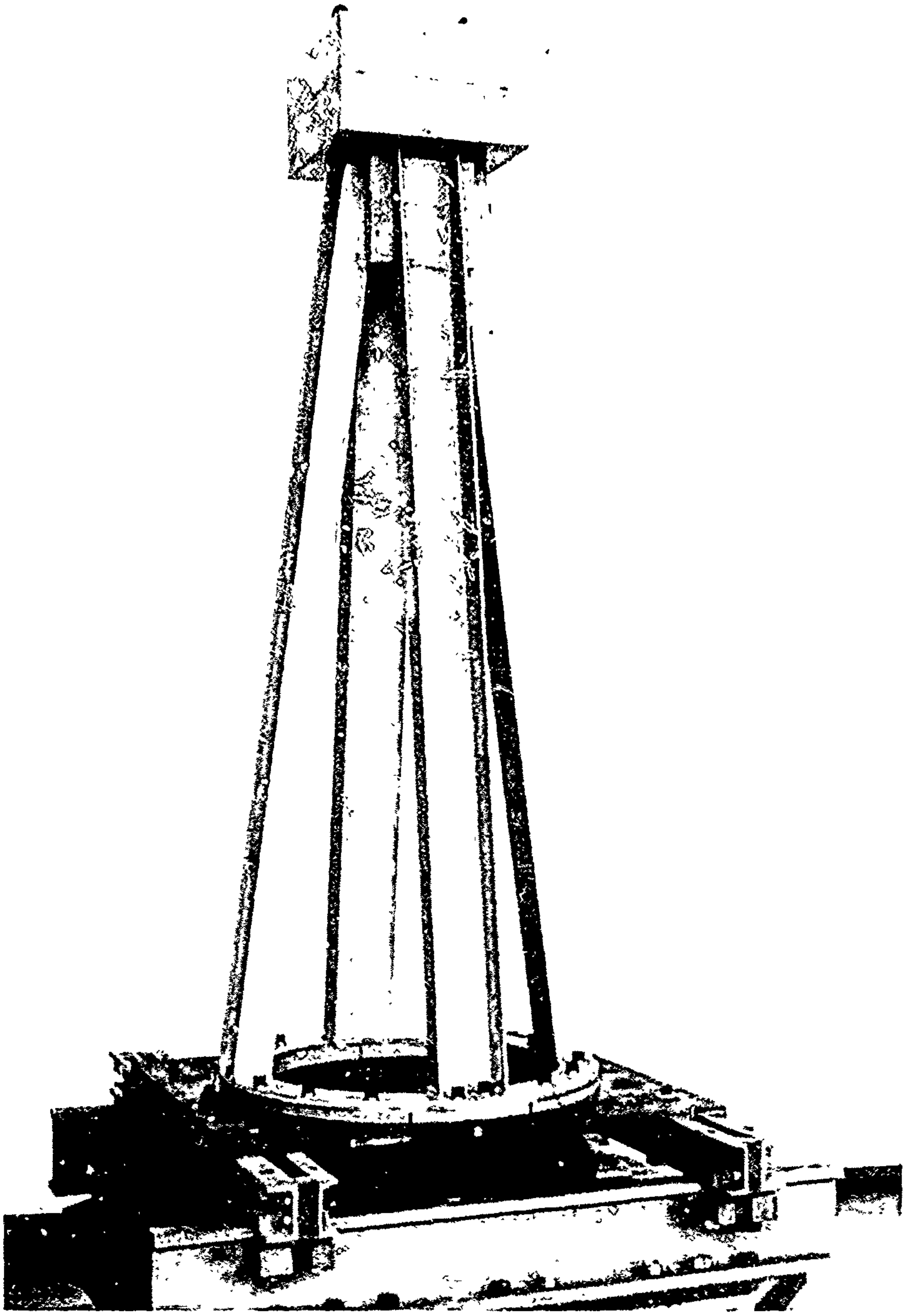

Fig. 19 — Test Structure No. 2 on the MWSM arranged for vertical shock.

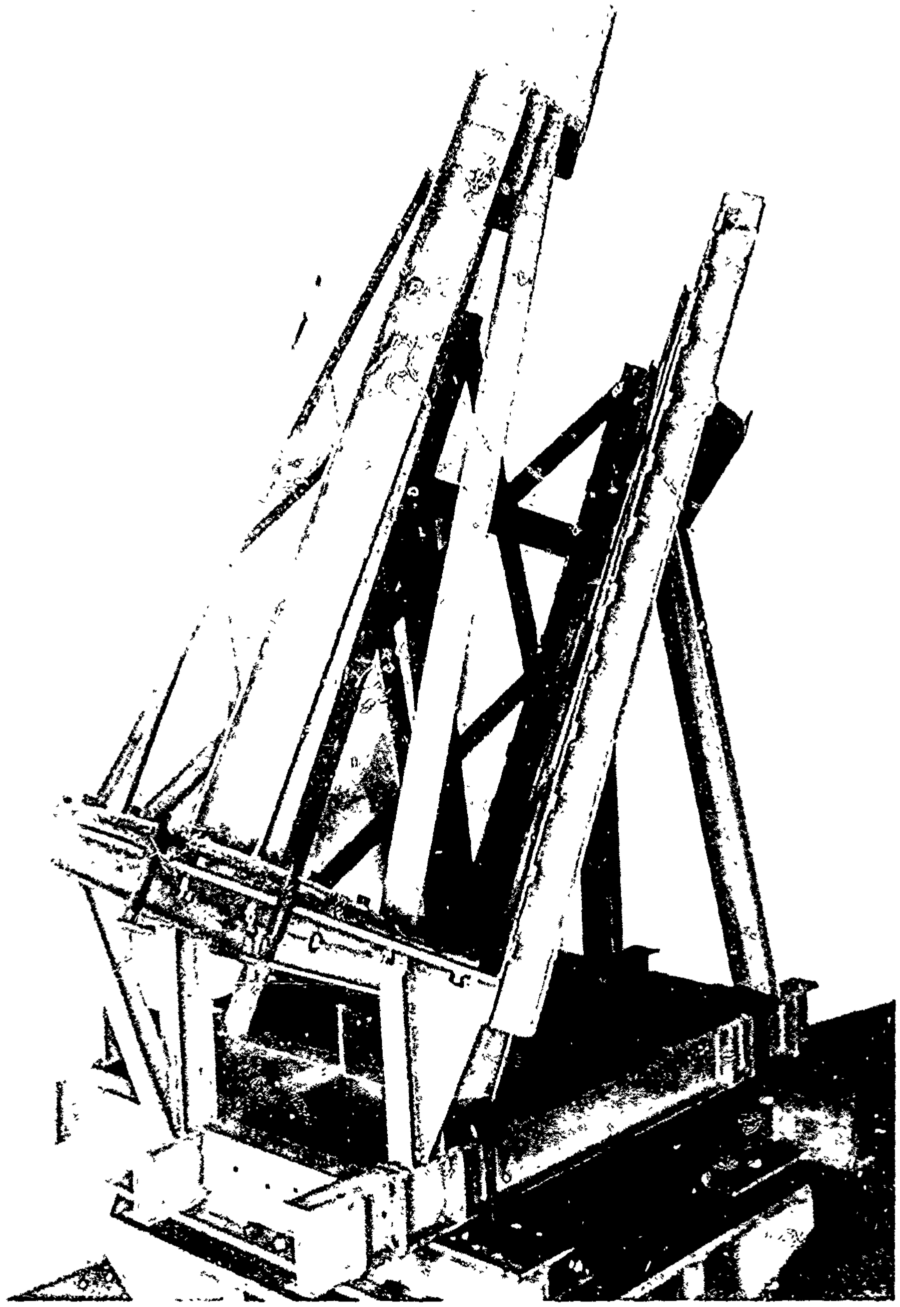

Fig. 20 — Test Structure No. 2 on the MWSM arranged for inclined shock.

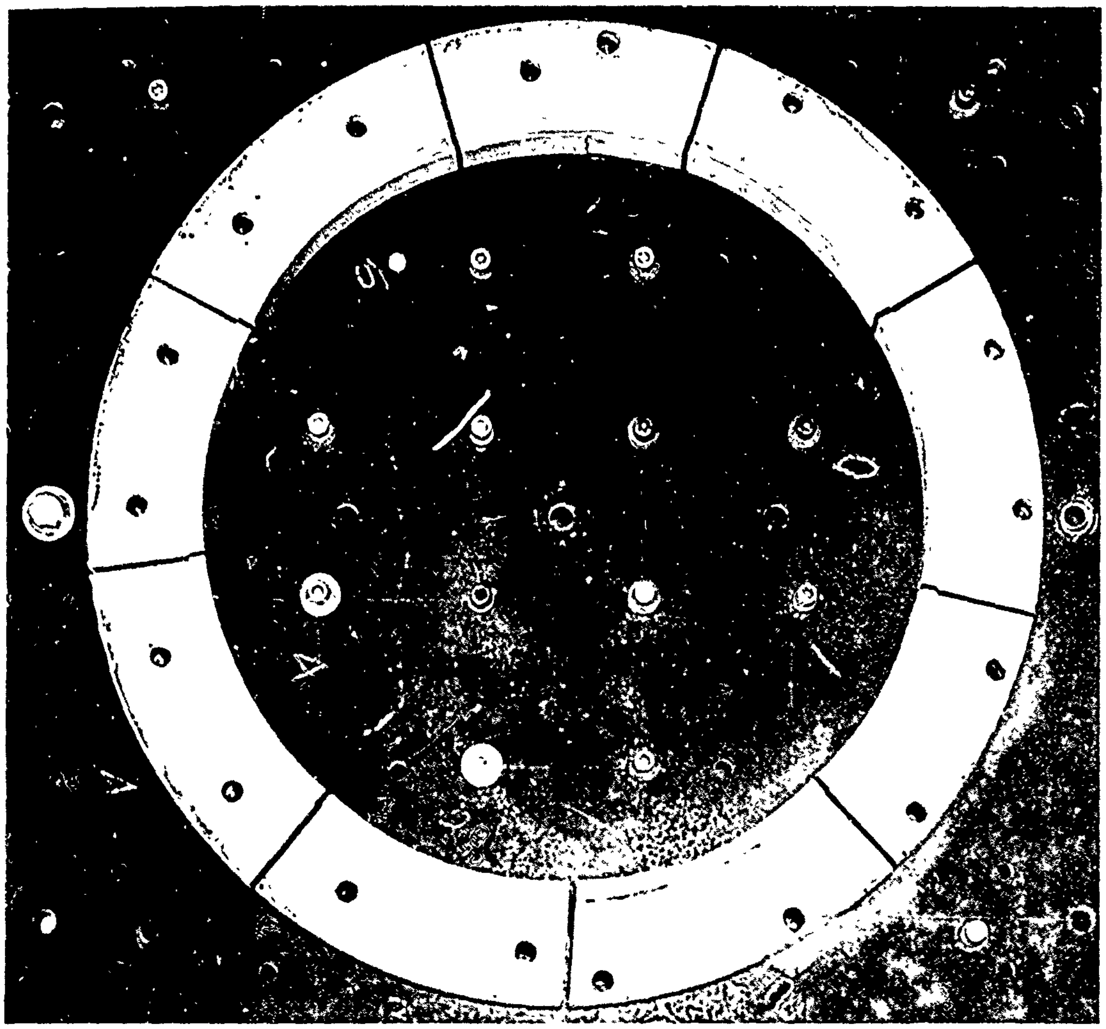

Fig. 21 — The chock pads of Test Structure No. 2 after the standard shock test. The markings visible around the outer edges of Pads (4 & 5, for example) are patchy discoloration rather than abrasions.

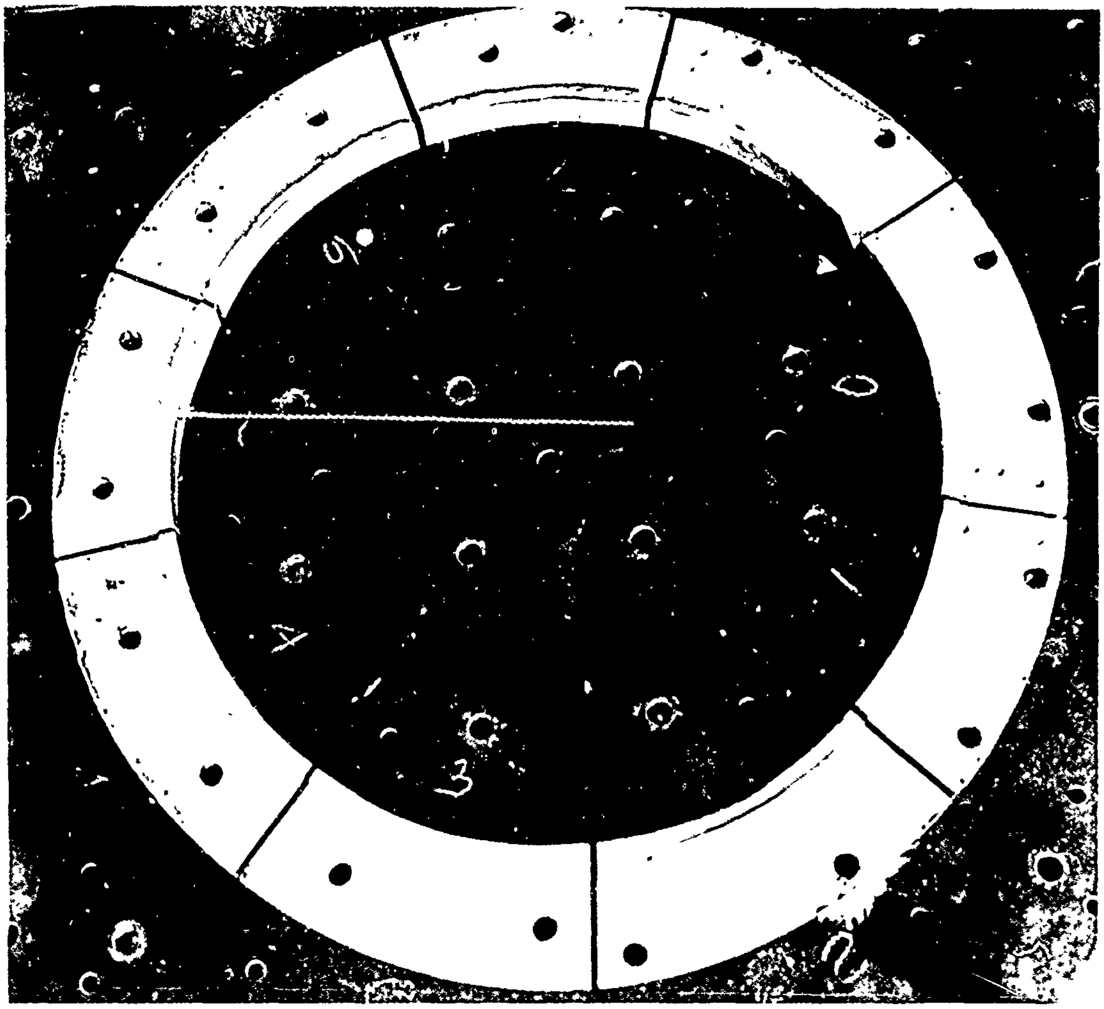

Fig. 22 — The chock pads of Test Structure No. 2 after completion of shock and vibration tests. The corner of Pad 8 spalled off on Blow 8, one of the extra blows with hold-down bolts loosened. No additional damage was caused by Blow 9.